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Division 2, National Defense Research Committee of the Office of Scientific Research and Development

MONTHLY REPORT NO. OTP-7 (OSRD NO. 4720)

ATI No 61319

ORDNANCE AND TERMINAL BALLISTICS

Volume 7. January 15 to February 15, 1945

A Compilation of Informal Reports Submitted in Advance of Formal Reports

Pertinent Service Projects

AC-73	OD-154
CE-36	OD-160
OD-75	NC-11
NC-12	

Copy No. 36

Division 2, National Defense Research Committee of the
Office of Scientific Research and Development

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6A

ORDNANCE AND TERMINAL BALLISTICS

Volume 7. January 15 to February 15, 1945

A Compilation of Informal Reports Submitted in
Advance of Formal Reports

Princeton Univ
Duke Univ

Pertinent Service Projects

AC-73	OD-154
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Approved on February 21, 1945
for submission to the Committee

E. B. Wilson Jr

E. B. Wilson, Jr., Chief
Division 2, NDRC
Effects of Impact and Explosion

The NDRC Technical Reports Section
for armor and ordnance edited
this report and prepared it for duplication.

Preface

This report is the seventh monthly report of Division 2, NDRC, on Ordnance and Terminal Ballistics, covering the period from January 15 to February 15, 1945. These monthly reports are compilations of informal reports submitted in advance of formal reports. In no case is it to be presumed that the work is complete or that the results reported are other than tentative.

The work described in this report is pertinent to the projects designated by the War Department Liaison Officer as AC-73, CE-36, OD-75, OD-154, OD-160, and to the projects designated by the Navy Department Liaison Officer as NO-11, NO-12. The work was performed under Contract OEMsr-260 with Princeton University and Contract OEMsr-1284 with Duke University. DA

Arrangement is by project rather than by contract in order that all material pertinent to a particular phase of the work may appear together. These monthly OTB reports are intended to give in some detail the results obtained during the preceding month by each of the contractors working on a particular project.

This bound copy is intended for the use only of those individuals and groups authorized to receive information about the activities of Division 2 in the entire field of Ordnance and Terminal Ballistics. It should not be shown to persons who are concerned with only a limited part of the work. Loose-leaf copies of the sections are available for distribution through liaison channels to those who have a legitimate interest in the results of work on individual projects.

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ADVANCE RELEASE: This information is tentative and subject to revision.

Princeton University
W. Bleakney, Supervisor

PENETRATION THEORY: ESTIMATES OF VELOCITY AND TIME DURING PENETRATION*

by R. A. Beth

Abstract

This paper summarizes the theory of the variation of the resisting force R during projectile penetration for three cases — (i) R is a constant, the Robins-Euler Theory; (ii) R is a function of the remaining velocity (sectional-pressure theories); and (iii) R is a function of the distance penetrated (sectional-energy theories).

Neither the theoretical nor an empirical approach has been sufficient to give a knowledge of R; however, the actual curve for R is expected to fall between those predicted by cases (ii) and (iii).

A knowledge of R would be a step toward solution of the practical problems of fuze setting, target design, and projectile design.

1. Introduction

The laws of variation of the resisting force during the penetration cycle of a projectile are not known. It has been necessary to accumulate a very large quantity of experimental data on penetrations and velocities and to attempt through these to assay the influence of target and projectile parameters. Our inability to apply the second law of motion has therefore resulted in this situation: we can only predict with confidence those cases in which the variables lie reasonably close to situations for which we have carefully measured data; this confidence decreases rapidly as greater extrapolation from previously measured combinations becomes necessary.

There are certain kinds of practical problems for which we do not even have previous measurements by which to make reasonable empirical predictions. Among these are:

(a) Setting of fuze. — The time of penetration has been sought in order to specify fuze settings for detonation at or near maximum penetration, expecially in concrete.

*This paper is a revision, with minor alterations, of a Division 2 contractor's informal memorandum — PMR-6 — of March 1944.

C O N F I D E N T I A L

(b) Design of composite targets. -- If a target consists of a combination of layers of earth and concrete, or concrete and steel, it is desired to estimate the over-all resistance from the available data on each separate material. This could be done, for example, by estimating the remaining velocity with which each layer after the first is attacked.

(c) Design of projectile. -- In order to design a projectile containing as much explosive as possible without undue weakening against deformation, it would be helpful to have reasonable estimates of the maximum force acting during penetration, especially in concrete.

It is the purpose of this paper to suggest methods by which reasonable upper and lower bounds may be given for the fundamental quantities upon which solution of these practical problems depends.

2. Penetration theory: Limiting cases

Assume that the following projectile parameters are constant during penetration:

W = weight of the projectile;

A = cross-sectional area of the projectile;

P = sectional pressure = W/A; and

P' = sectional density = P/g, where g is the acceleration due to gravity.

Denote the kinematic variables during penetration by

x = the distance penetrated;

v = the remaining velocity; and

t = the time.

If v_0 is the striking velocity, x_1 the maximum penetration, and t_1 the time of penetration, then

$$\left.\begin{array}{l} x = 0 \\ v = v_0 \end{array}\right\} \text{ for } t = 0,$$

$$\left.\begin{array}{l} x = x_1 \\ v = 0 \end{array}\right\} \text{ for } t = t_1.$$

The relation between x, v, t, and the resisting force per unit area, R, during the motion in the target is given by Newton's second law, which we write in the form

$$\text{(1)} \qquad P' \frac{d^2x}{dt^2} = P'v \frac{dv}{dx} = -R.$$

It is usual in attempting to construct a theory of penetration to assume a physically plausible form for the resistance function $\underline{R}$ involving only constant parameters, which are to be evaluated after the integration from selected penetration measurements. These attempts, notably the Euler and Poncelet theories, then prescribe a functional connection between x_1 and v_o which it is difficult or impossible to reconcile with the observed curves.

Alternatively, the observed curve connecting x_1 and v_o can often be expressed algebraically as an empirical penetration formula without reference to the equation of motion, Eq. (1). The resistance function $\underline{R}$ is not uniquely determined by the empirical formula or curve connecting x_1 and v_o.

Thus neither the theoretical nor the empirical approach has been sufficient to provide a knowledge of $\underline{R}$ or, what is equivalent, of $\underline{x}$, $\underline{v}$, and $\underline{t}$, <u>during</u> penetration. It is of interest to attempt to combine the two, supplementing the empirical knowledge of the x_1, v_o-relation by <u>just enough</u> assumptions about the form of $\underline{R}$ to determine the latter uniquely.

If the penetration x_1 has been measured for only one value of v_o, then the simplest sufficient supplementary assumption regarding $\underline{R}$ is

(<u>a</u>) <u>The resistance is constant.</u> — With $R = c$ where $\underline{c}$ is a constant, Eq. (1) becomes

$$P'v \frac{dv}{dx} = -c.$$

Separating variables and integrating we get

$$c \int_0^{x_1} dx = -P' \int_{v_o}^{0} v\,dv = P' \int_0^{v_o} v\,dv,$$

which gives

$$cx_1 = \tfrac{1}{2} P' v_o^2 \quad \text{(work done = striking kinetic energy);}$$

or

$$P' v_o^2 = 2cx_1.$$

We may also write the indefinite integrals

$$c\int_0^x dx = -P'\int_{v_0}^{v} v\,dv = P'\int_{v}^{v_0} v\,dv.$$

Integrating, we get

$$2cx = P'(v_0^2 - v^2),$$

$$2cx = P'v_0^2 - P'v^2,$$

$$2cx = 2cx_1 - P'v^2,$$

or

$$2c(x_1 - x) = P'v^2.$$

This is essentially the Robins-Euler theory. It is more interesting as the simplest possible reference case than for practical applications.

If the penetration x_1 has been measured for enough values of v_0 so that it may be considered to be known as a smooth curve starting as $x_1 = 0$ and $v_0 = 0$, then two equally simple sufficient assumptions regarding R are

(b) The resistance depends only on v. -- Integrating Eq. (1) for $R = f(v)$ gives

$$x_1 = P'\int_0^{v_0}\frac{v\,dv}{f(v)} \equiv F_P(v_0^2);$$

hence

$$f(v_0) = P'v_0\frac{dv_0}{dx_1}.$$

Also,

$$x = x_1 - F_P(v^2).$$

In this case x_1/P depends only on v_0. The penetration theories that fall in this category are called sectional pressure theories.

(c) The resistance depends only on x. — Integrating Eq. (1) for $R = g(x)$ gives

$$v_0^2 = \frac{2}{P'} \int_0^{x_1} g(x)\, dx \equiv G_p(x_1);$$

hence

$$g(x_1) = P' v_0 \frac{dv_0}{dx_1} .$$

Also,

$$v^2 = v_0^2 - G_p(x).$$

In this case $\frac{1}{2}P' v_0^2$ depends only on x_1. The penetration theories that fall in this category may be called sectional energy theories.

Figure 1 illustrates each of these three cases. Note that the functions $F_p(v_0^2)$ and $G_p(x_1)$ as well as the constant c are determined quantitatively in each case from the observed v_0^2 plotted against x_1 in the diagrams of row (i). Then the graph of v^2 against x for a particular penetration is drawn in row (ii) by transposing the corresponding graph in row (i) according to the formulas derived in the foregoing. From row (ii) it is possible to obtain

$$t = \int_0^x \frac{dx}{v}$$

as a function of x by integrating numerically if necessary. The velocity v is then plotted against the time t in row (iii). The time of penetration t_1 is then given by the t-intercept of the last curves, and the area under them represents

$$x_1 = \int_0^{t_1} v\,dt.$$

The following qualitative argument may be made that the $R = f(v)$ case and the $R = g(x)$ case give limits for v and t_1 between which the physically correct values must lie if

(1) the resistance actually depends only on x and v, that is, $R = R(x,v)$;

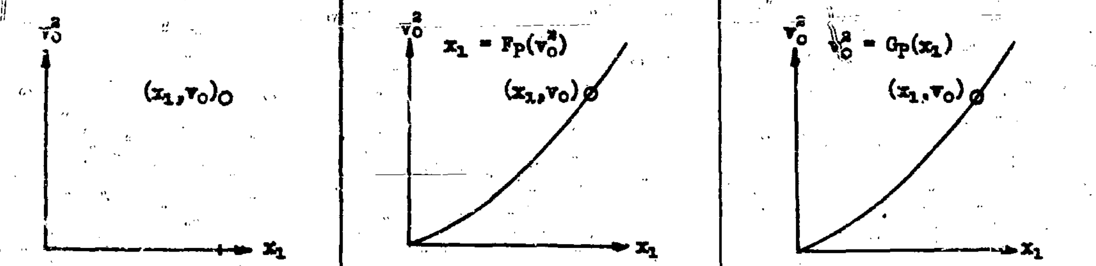
(2) the resistance for a given v cannot decrease as x increases and, for a given x cannot increase as v decreases, that is,

$$\frac{\partial R}{\partial x} \geq 0, \qquad \frac{\partial R}{\partial v} \geq 0.$$

Fig. 1. Penetration theories: summary of three cases.

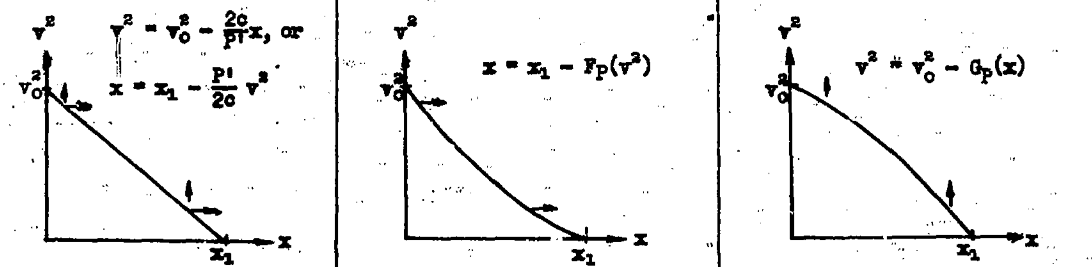
Robins-Euler Theory $R = c$	Sectional Pressure Theories $R = f(v)$	Sectional Energy Theories $R = g(x)$

(i) Observed relation between striking velocity v_0 and maximum penetration x_1.



(ia) (ib) (ic)

(ii) Relation between v^2 and x during penetration; derived from (i) for fixed x_1 and v_0. For larger values of x_1 (or v_0), shift curve as shown by arrows.
Slope $= 2 \times$ acceleration.



(iia)

(iib) Rotate (ib) about vertical axis to get (iib).

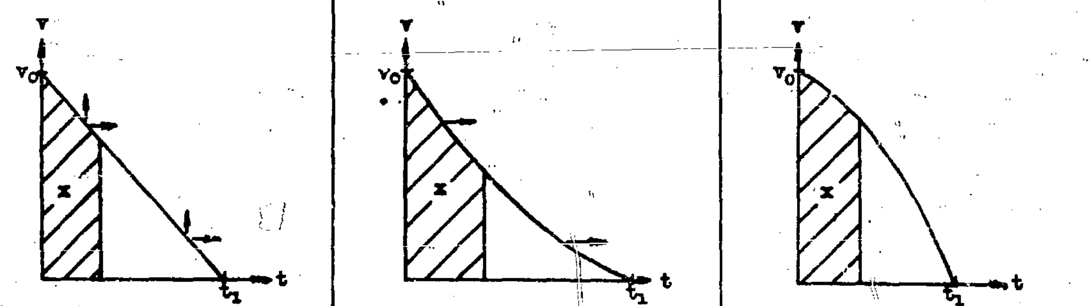
(iic) Rotate (ic) about horizontal axis to get (iic).

(iii) Relation between v and t during penetration; derived from (ii) for fixed x_1 and v_0.

$$t = \int_0^x \frac{dx}{v}, \quad x = \int_0^t v\,dt, \quad \text{slope} = \text{acceleration.}$$

Time of penetration t_1 is the t-intercept.

$v_0 t_1 / x_1$ = area of rectangle/area under curve = pure number.



(iiia) $v_0 t_1 / x_1 = 2$.

(iiib) For $df/dv > 0$, (iib) and (iiib) are concave upward, and $v_0 t_1 / x_1 > 2$.

(iiic) For $dg/dx > 0$, (iic) and (iiic) are concave downward, and $v_0 t_1 / x_1 < 2$.

Both assumptions are physically plausible. If the resisting force increases with x the negative slopes in graphs (ii) and (iii) [decelerations] tend to increase in steepness as x and t increase; in other words, the curves tend to be concave downward. Conversely, if the resisting force decreases with decreasing v, the negative slopes in (ii) and (iii) tend to become less steep as x and t increase, thus tending to make the curves concave upward. These tendencies are illustrated in the cases drawn, in which the resisting force depends only on x or only on v, and it is plausible that the tendencies remain when R depends on both under the assumption (2).

In Fig. 2, the curves (iib) and (iic) from Fig. 1 for the R = f(v) case and the R = g(x) case are plotted together. On the foregoing qualitative argument, the actual curve for R = R(x,v) may be expected to fall between the two curves given, as is suggested by the dashed curve (Fig. 2).

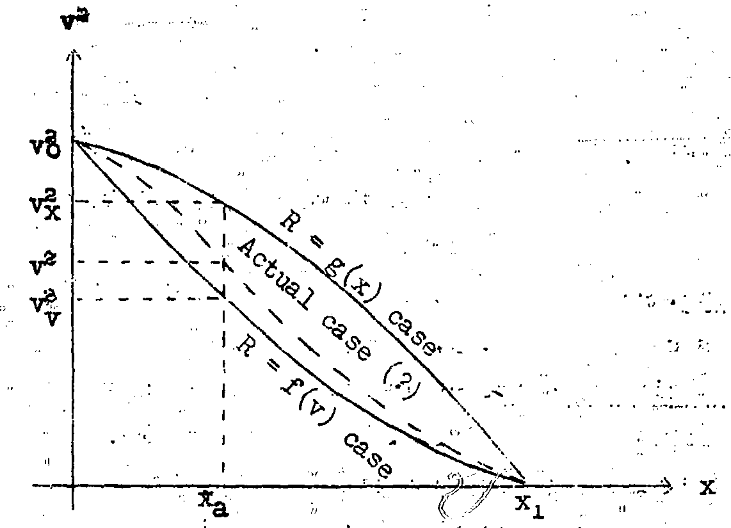


Fig. 2. Method of estimating limits for the remaining velocity v for penetration $x = x_a$. Note that $v_v \leq v \leq v_x$.

In Fig. 3 the curves (iii) from Fig. 1 for the R = f(v) case and the R = g(x) case are plotted together. The area under each curve represents the maximum penetration x_1, which is the same for both, being assumed known for the given striking velocity v_o. Here again the dashed curve suggests a possible true case for the same value of x_1.

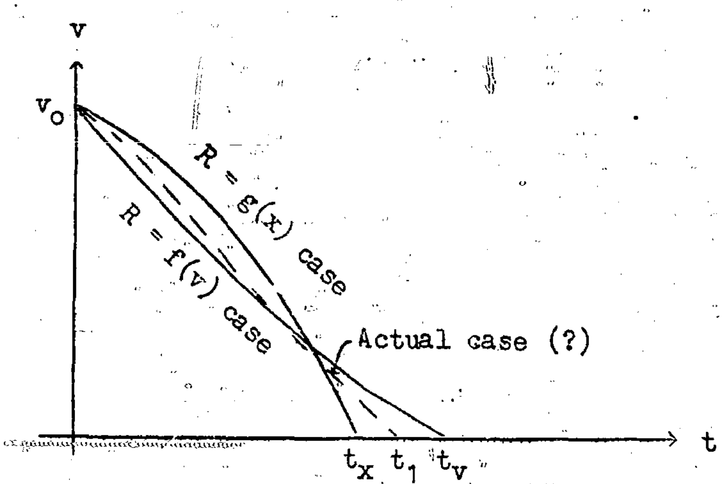


Fig. 3. Method of estimating limits for the time of penetration t_1. Note that $t_x \leq t_1 \leq t_v$.

3. Applications

From the graphs in Figs. 2 and 3 it is possible to get reasonable, though approximate, answers to problems like those mentioned in the Introduction.

(a) Setting of fuze. — Upper and lower limits for the time of penetration can be estimated as shown in Fig. 3.

(b) Design of composite targets. — The over-all resistance can be determined from curves like those of Fig. 2. If, for example, a layer of concrete of thickness $e = x_a$ is backed by a steel plate, then Fig. 2 should be made for concrete, and the steel should be assessed in terms of the estimated striking velocity v_1', where $v_v \leq v_1' \leq v_x$. This procedure may be sufficiently good in many practical cases without taking account of the altered internal restraints in each medium occasioned by the interface.

(c) Design of projectile. — The acceleration of the projectile is given by one-half the slope of the curve in Fig. 2, and directly by the slope in Fig. 3. Thus the maximum resisting force acting on the projectile during the penetration cycle may be roughly estimated from the steepest portion of the hypothetical dashed curves, allowance being made for some appropriate safety factor (for example, 50%). The derivations in Sec. 2

show that for both the R = f(v) case and the R = g(x) case maximum deceleration encountered by the projectile is given by the maximum value of $v_o dv_o/dx_1$ which is one-half the maximum slope of the experimental curves (i) in Fig. 1.

4. Concluding remarks

(a) It is common to assume, as has been done in the foregoing, that the resistance R can depend only on x and v.[1] Even this assumption, which in its general form already prevents us from integrating the equation of motion, Eq. (1), is probably too simple, since it implies that the projectile only encounters essentially undisturbed target material during penetration. There is, however, reason to expect that energy and momentum transferred to target material at earlier stages in the penetration cycle may serve to reduce both the crushing and the inertial resistance of the target at later stages. Thus the right-hand side of Eq. (1) should depend on "previous history" as well as on x and v. It is not obvious how this hypothesis can be put in mathematical form. It suggests that the penetration cycle may involve a "transient" stage at the beginning during which the disturbance in the target material is set up; a subsequent "steady-state" stage during which the projectile-target interaction depends in some continuous way on relative motions; and possibly a final "transient" stage when the projectile deceleration suddenly (discontinuously) drops from a finite value to zero while the disturbance of the target material tapers off in some rapid but continuous way. It is, nevertheless, felt that these considerations would not greatly modify the practical applicability of the methods described, since they make use of actually measured rather than postulated relations between x_1 and v_o.

(b) Just as the assumption in the R = c case can be tested by measuring x_1 for more than one value of v_o, so the assumptions in the R = f(v) and R = g(x) cases can be tested by measuring x_1, v_o-curves for more than one value of P. Some work on this has been done on concrete with the indication that the truth lies between the R = f(v) case and the R = g(x) case. It may

1/ For example, see "Terminal ballistics I," by H. P. Robertson, Jan. 1941, unclassified. Submitted by the Committee on PPAB (later CFD) to Chief of Engineers, U.S. Army.

be possible to narrow down the assumptions by using such data, but the methods have not been clearly formulated as yet.

(c) A better analysis may result from present attempts to measure t_1 directly. Preliminary indications are that for concrete $v_0 t_1/x_1$ lies in the vicinity of 2.0 to 2.5.

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February 15, 1945

Projects OD-75, NO-11

ADVANCE RELEASE: This information is tentative and subject to revision.

Princeton University
W. Bleakney, Supervisor

TERMINAL BALLISTICS OF TUNGSTEN CARBIDE PROJECTILES: SURVEY AND NOSE-SHAPE TESTS

by C. W. Curtis, R. J. Emrich, and J. R. Sproule

Abstract

Eighty monobloc caliber .244 projectiles of one nose shape have been tested in a survey against 2-caliber, 4-caliber, and 6-caliber thick homogeneous armor at striking velocities from 2500 ft/sec to 5000 ft/sec and at obliquities of attack from 0° to 65°. The regions of values of these variables in which perforation is achieved and in which shatter occurs have been mapped out. The effect of shatter on the perforation performance is similar in nature to that occurring with monobloc steel projectiles. Under certain conditions an increase in perforation limit energy at least as great as 80 percent can be attributed to shatter.

Twenty-five each of five projectile designs having widely different nose shapes, but all having the same weight and diameter as the survey-tested projectiles, have been fired against the same plates and, in addition, against an 8-caliber thick plate. Nose shape was found to affect strongly the shatter velocity and thereby the perforation performance of the projectiles. When fired above 3000 ft/sec and at obliquities of attack of 40° and less as a monobloc without cap, sheath, or carrier, projectiles of nose shape 1.25/2.50 secant ogive or 4.25/4.25 tangent ogive perforate greater thicknesses of armor than is possible with projectiles having less pointed noses; but at obliquities of attack greater than 40°, where all shatter, no large effect in perforation limit was noted.

When all obliquities of attack are considered, some means of avoiding shatter other than changes in nose shape must be employed when tungsten carbide is fired in the hypervelocity region.

1. Considerations of terminal ballistics of tungsten carbide

The factors in the design of a projectile with a tungsten carbide core that affect its performance against armor plate are:

(a) Size of core;

(b) Shape of core: nose shape and length;

(c) Physical properties: strength and density;

(d) Amount of cap and sheath.

The thickness of plate perforated will depend on the plate hardness, the projectile properties just listed, and the conditions of impact, that is, the striking velocity and obliquity of attack.

The design of the projectile that when fired from a given gun perforates the maximum thickness of armor at fighting ranges must take interior and exterior ballistic behavior into account as well as terminal ballistic behavior. However, if the weight and diameter of various projectiles are held constant and only the shape is varied, the interior and exterior ballistics are the same, and a comparison of the projectiles is possible from the terminal ballistic behavior alone.

2. Survey test

As the first step in determining the combination of factors that would give optimum terminal ballistics, a survey of the performance of a particular core has been made over ranges of variation of striking velocity, obliquity of attack, and plate thickness. The ranges of these variables were chosen to include plate thicknesses (relative to the core diameter used) and obliquities that might be met and defeated in tactical combat with hypervelocity projectiles; all other factors were kept constant for this survey test.

The values chosen for the fixed variables and the ranges of variation of the others are given in Table I.

The contour of the projectile (type M-24-20) is shown in Fig. 1. The particular projectile chosen has a diameter of 0.244 in. and is nearly a scale model of the core specified by the British Army for the 6-pdr D.S. Mk I projectile, differing very slightly in nose shape — see Fig. 2.

The projectiles were threaded for a distance of 0.7 caliber from the base to allow them to be fired as cores in a caliber .50 sabot-projectile which discarded its sabot so that only the bare core impacted the target. Figure 3 is a shop drawing of the caliber .50 sabot-projectile[1] with which velocities as high as 5200 ft/sec were successfully obtained.

[1] The sabot is a modification of a design suggested by the University of New Mexico under contract to Division 1, NDRC.

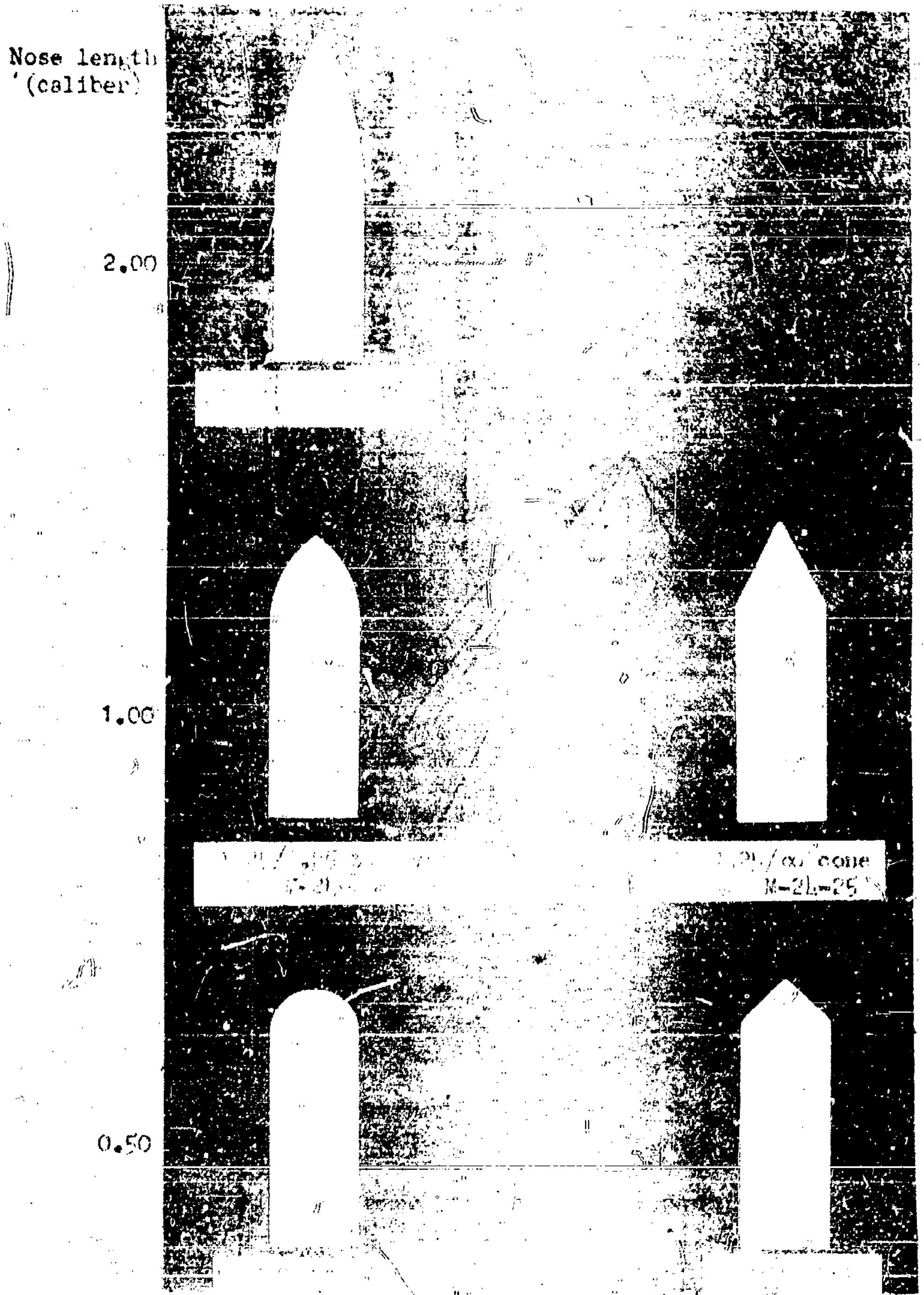

Fig.

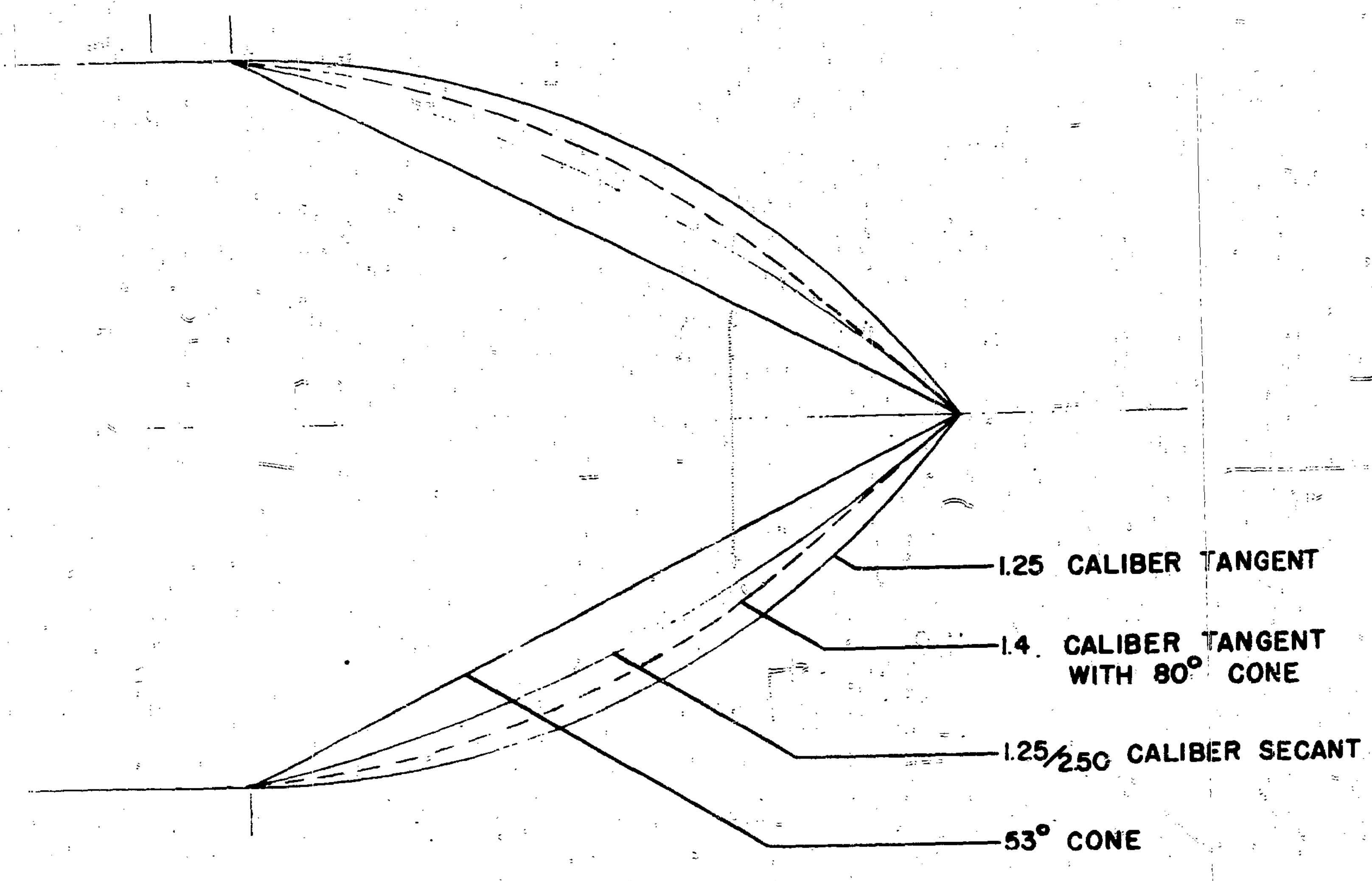

Fig. 2. Comparison of nose shapes of 1-caliber length with British 6-pdr D.S. core nose shape.

Princeton University Station
Division 2
NDRC

Table I. Values of terminal ballistic variables -- striking velocity, obliquity of attack, and plate thickness -- in survey test of caliber .244 projectile type M-24-20.

The velocity range is from just below the perforation limit to 4400 ft/sec in 400-ft/sec intervals.

Composition: 89% WC, 11% Co

Nose shape: 1.25 caliber radius tangent ogive

Length: 2.26 calibers (ogive to base)

w/d^3: 1.15 lb/in^3

Cap, carrier, sheath: none

Armor plate hardness: BHN 250 to 270

Plate Thickness		Obliquity of Attack (deg)							
(in.)	(caliber)	0	30	40	45	50	55	60	65
2.01	8.24								
1.50	6.15	×	×						
1.01	4.14	×	×	×	×				
0.50	2.06	×	×		×	×	×	×	×

Striking yaw was measured 2 ft ahead of the target and was generally less than 5°; velocities were measured 4 ft ahead of the target by light screens on a 4-ft base line.

The results of the survey test are given graphically in Fig. 4, where for each plate thickness, striking velocity is plotted against sec θ (where θ is the obliquity of attack). The type of hole in the armor made by each shot was classified into one of four groups:

(a) No perforation, smooth surfaced hole of approximate projectile diameter (nonshatter);

(b) Perforation, smooth surfaced hole of approximate projectile diameter (nonshatter);

(c) No perforation, rough surfaced, oversized hole (shatter);

(d) Perforation, rough surfaced, oversized hole (shatter).

Each shot is plotted with a symbol representing the result on the armor; no difficulty was experienced in distinguishing between smooth-surfaced and rough-surfaced holes except in the shaded regions in Fig. 4. Within the wide spacing of the variables, straight lines could be drawn to indicate the nonshatter perforation limits. In the case of 2.06-caliber plate,

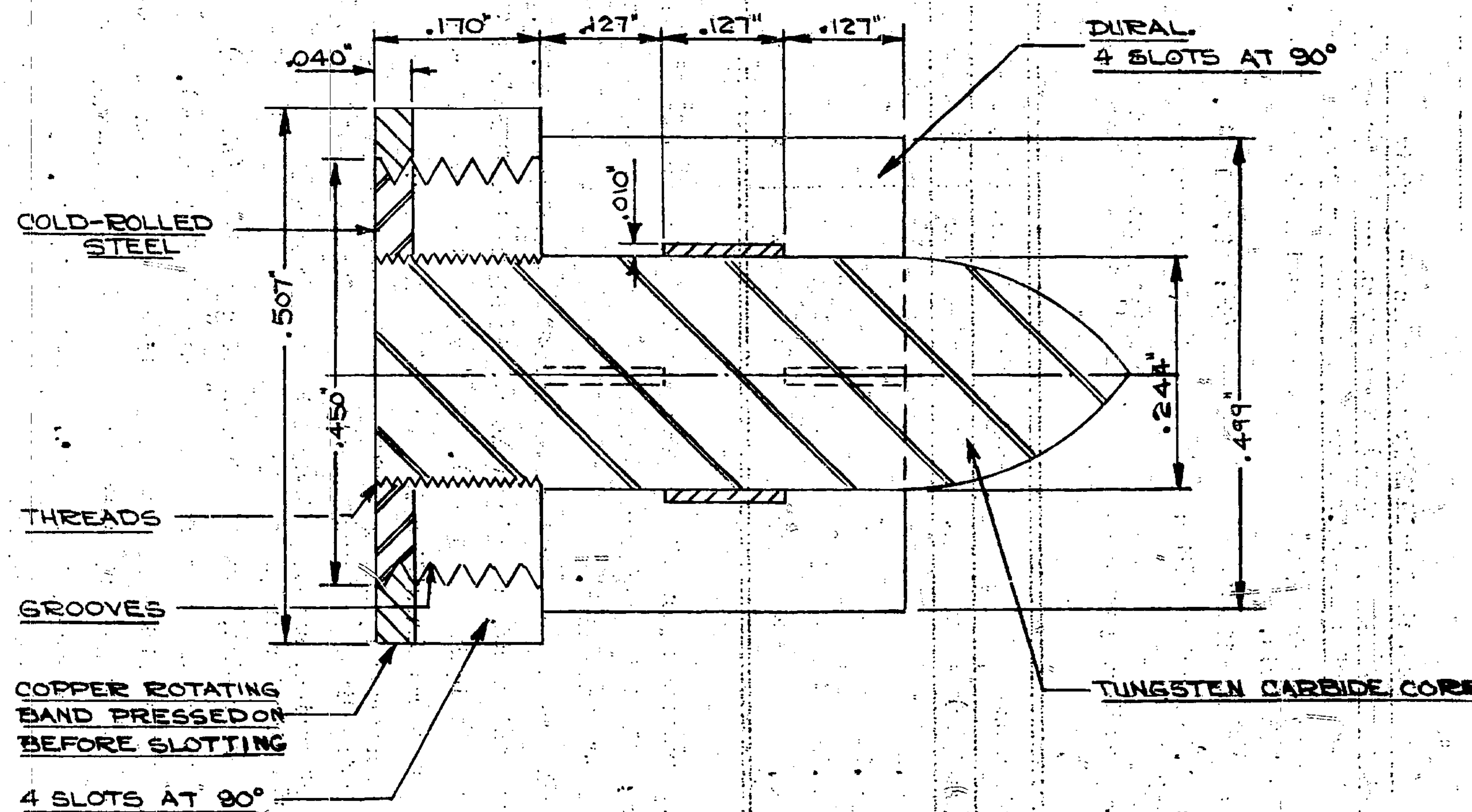

Fig. 3. Hypervelocity caliber .50 sabot projectile 8-50-5 with caliber .244 tungsten carbide core.

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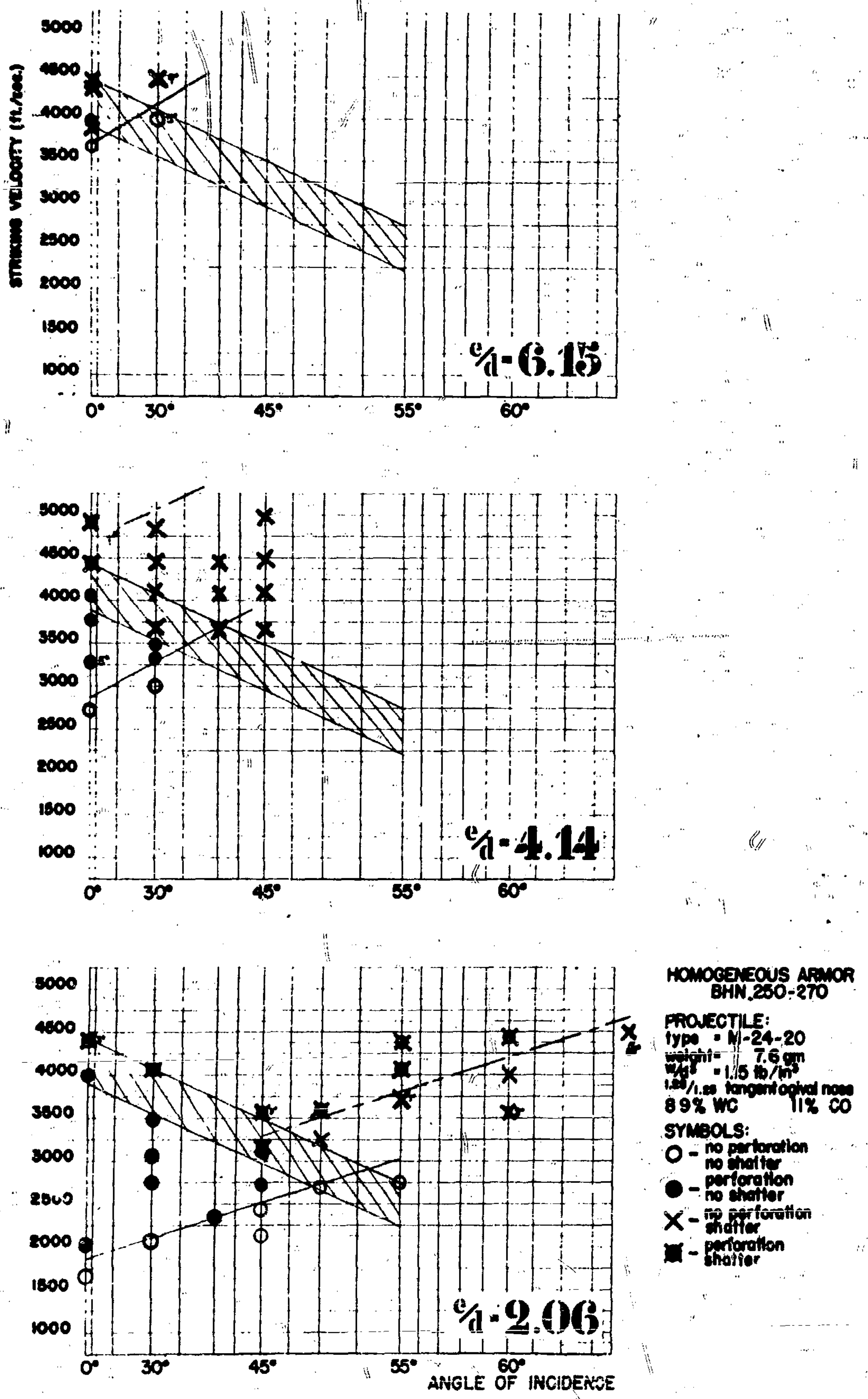

FIG. 4: SURVEY OF PERFORMANCE OF MONOBLOC CALIBER .244 TUNGSTEN CARBIDE PROJECTILE

perforation limits obtained with the shattered projectile at high obliquities have been indicated with a broken line.

Recovery of projectiles after impact was attempted, but generally without success. Although smooth-holed perforations were frequently accompanied by the recovery of the projectile nose intact, the remainder of the projectiles apparently disintegrated to a fine powder which could be swept up from the vicinity of the target after a day's firing. A spark shadowgraph apparatus designed to measure the velocity of the projectile after perforating the armor also indicated the condition of the projectile after impact; two examples of the records obtained with the apparatus are given in Figs. 5 and 6, the latter showing the emergent projectile broken into very small pieces.

3. Nose-shape test

With the survey test as a basis, the effects of changes in the nose shape of the projectile have been studied.

If the profile of the nose is the arc of a circle, its shape may be specified by two quantities: the length λ of the nose and the radius R of the circle defining the curvature of the nose; both λ and R are lengths,

---

Fig. 5. Spark shadowgraph record of caliber .244 tungsten carbide projectile after perforation of armor. Projectile type M-24-22, nose length 2 calibers, tangent ogive. Striking velocity 4132 ft/sec, 6.15-caliber plate at 0° obliquity of attack. Smooth hole perforation. The record was made approximately 30 in. behind the target.

See p. 19.

Fig. 6. Spark shadowgraph record of caliber .244 tungsten carbide projectile after perforation of armor. Projectile type M-24-20, nose length 1 caliber, tangent ogive. Striking velocity 4896 ft/sec, 6.15-caliber plate at 0° obliquity of attack. Shatter hole perforation. The record was made approximately 30 in. behind the target. The larger pieces appearing in the picture are probably plate rather than projectile fragments.

See p. 21.

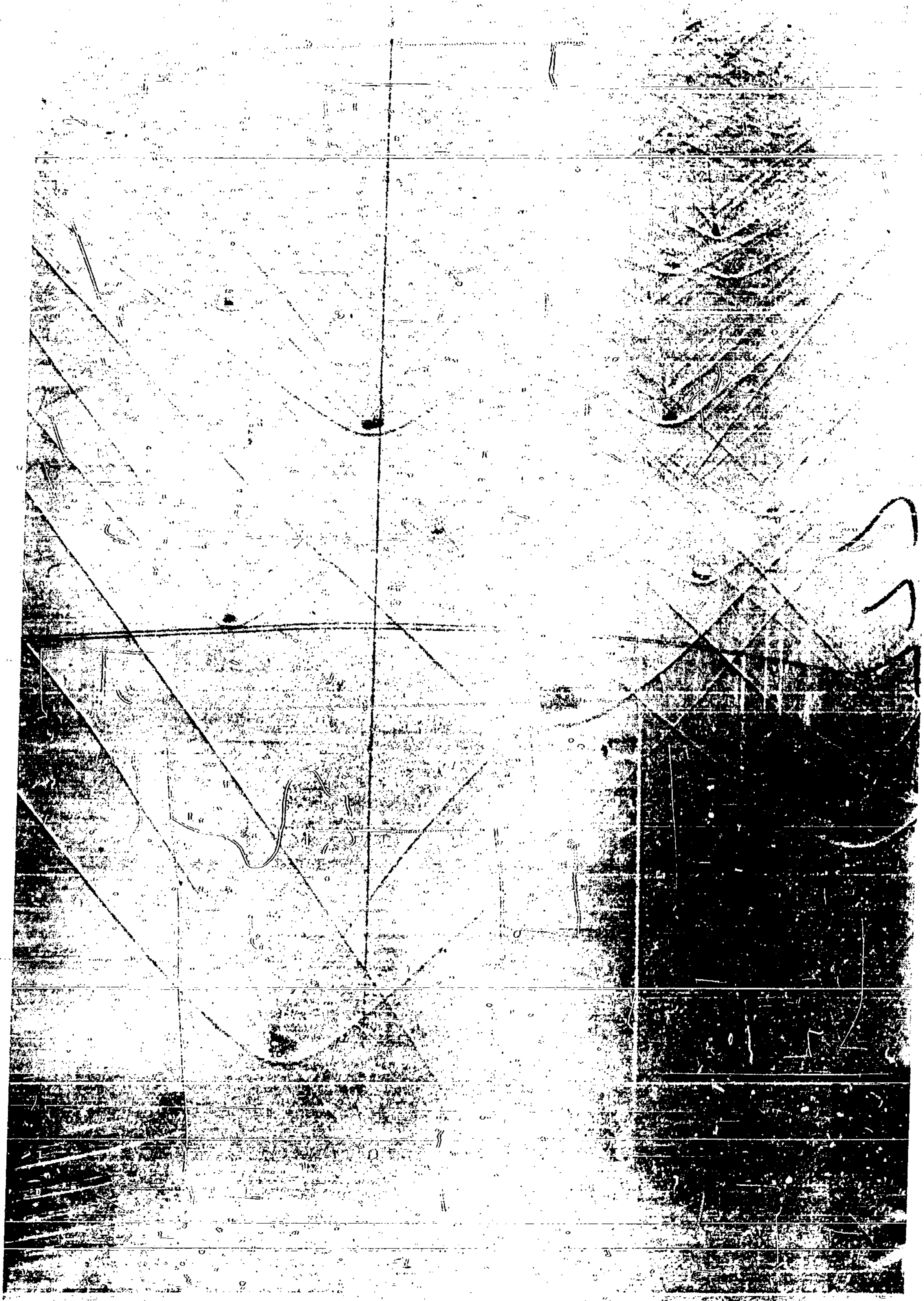

FIG. 6.

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expressed in calibers. Usually, instead of the length of the nose, λ, the radius r (expressed in calibers) of the circle required to give a tangent ogival nose of length λ is specified. The quantities r and λ are connected by the relation $\lambda = \sqrt{r - \frac{1}{4}}$. The nose shape is thus specified as r/R. The conical nose and the tangent ogival nose are special cases, specified as r/∞ and r/r, respectively.

From the foregoing varieties of shapes, the basis chosen for varying the nose shape was to select wide variations in (a) nose length λ, and (b) angle ϕ of the tip, from the shape specified for the British 6-pdr D.S. Mk I core. The six nose shapes listed in Table II have been used; the contours are compared in Fig. 1. The core nose shape of the 6-pdr D.S. is a 1.40/1.40 ogive with an 80° cone ($\phi = 80°$) ground on the point. That it is a shape intermediate between the 1.25/1.25 and 1.25/2.50 may be seen from Fig. 2 where it and the three nose shapes of 1-caliber length are superposed for comparison.

In varying the nose shape, ambiguity arises as to what part of the projectile length should be held constant — the over-all length, the length of the cylindrical section, or the length of the equivalent cylinder, that is, the cylinder with volume equal to the volume of the total projectile. The last possibility, which is the same as holding the weight of the projectile constant, has been chosen.

Table II. Description of nose shapes of caliber .244 tungsten carbide projectiles.

λ Nose length (caliber).

ϕ Included angle at tip of cone (deg)

r radius to give tangent ogival nose of length λ (caliber)

The symbols for the different shapes are Princeton type designations.

Nose Length (caliber)		Tangent Ogive			Secant Ogive			Cone		
λ	r	r/R	ϕ (deg)	Type	r/R	ϕ (deg)	Type	r/R	ϕ (deg)	Type
0.50	0.50	0.50/0.50	180	M-24-18	—	—	—	0.50/∞	90	M-24-24
1.00	1.25	1.25/1.25	106.3	M-24-20	1.25/2.50	80	M-24-23	1.25/∞	53.1	M-24-25
2.00	4.25	4.25/4.25	56.1	M-24-22	—	—	—	—	—	—

The values of the other factors relating to the design of the projectiles, which were held constant, are given in Table I. The projectiles were fired as cores in the same type of caliber .50 sabot against the same armor plates used in the survey test.

Because they have the same weight and diameter, the "best" projectile — that is, the "best" nose shape — may be chosen from the group tested on the basis of the amount of armor perforated at a given striking velocity and obliquity of attack. Hence, each projectile type was fired at velocities and obliquities near the perforation limits found in the survey test. It was sought to find for each type any conditions, if they existed, in which (a) perforation occurred under conditions where the survey-tested type failed, or (b) failure occurred under conditions where the survey-tested type perforated, or (c) performance occurred equal to that of the survey-tested type on either side of the perforation limit. Within the wide spacing of variables used, only marked and outstanding differences in performance would be expected to appear. Two types indicated better performance than the survey-tested type at 4-caliber plate and intermediate obliquities, and the range of velocity and obliquity over which this better performance occurred was explored.

To indicate the perforation performance of the different shapes we have used the following symbols:

$P_{e,\theta,v}$, Perforation achieved for plate thickness e, obliquity of attack θ, and striking velocity v;

$F_{e,\theta,v}$, Failure to perforate under given conditions.

Although 80 projectiles were fired in the survey test and only 25 of each of the other types were used in the nose-shape test, the perforation performance of each of the nose-shape types may be implied over the entire survey region through application of the following postulates:

(i) $P_{e,\theta,v}$ implies $P_{\theta,v}$ for all thinner plate;

(ii) $P_{e,\theta,v}$ implies $P_{e,v}$ for all lower obliquities;

(iii) $F_{e,\theta,v}$ implies $F_{\theta,v}$ for all thicker plate;

(iv) $F_{e,\theta,v}$ implies $F_{e,v}$ for all higher obliquities.

Note that because of the possibility of a shatter gap no implication may be drawn with regard to another velocity from a value of $P_{e,\theta,v}$ or of $F_{e,\theta,v}$.

The results against 2-caliber, 4-caliber, and 6-caliber plate are contained in the graphs of Figs. 7, 8, and 9. Striking velocity is plotted against obliquity of attack, and the type of hole in the armor is distinguished as nonshatter or shatter in the sense discussed in Sec. 2. The perforation limits and shatter-velocity band resulting from the survey test on the same armor plates (Fig. 4) are drawn in again on the graphs of the nose-shape test (Figs. 7, 8, and 9) to allow comparison.

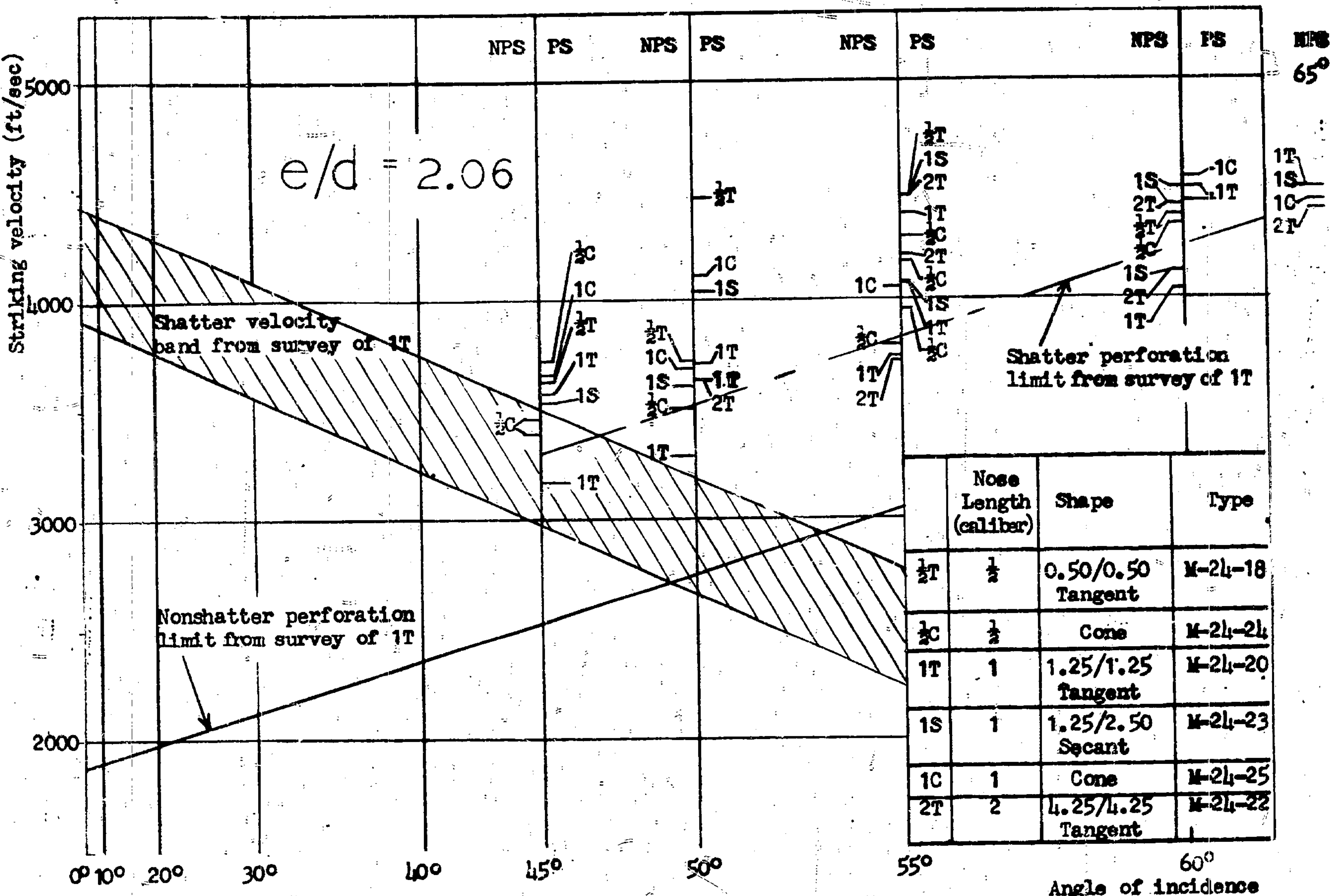
Six shots with the 2-caliber length tangent ogival nosed projectile M-24-22 were made against 8.24-caliber armor plate (BHN 280) at 0° obliquity of attack. Three shots struck with 5° yaw at velocities of 4230 ft/sec, 4470 ft/sec, and 4950 ft/sec and failed to perforate; the remaining struck with no yaw at 4430 ft/sec, 4900 ft/sec, and 5210 ft/sec and perforated without shatter. The projectile nose was recovered intact after the shots at 4430 ft/sec and 4900 ft/sec.

Although the performance of the projectiles of 1-caliber nose length with secant ogive and with cone -- M-24-23 and M-24-25 -- against 6-caliber plate at 0° obliquity of attack indicated that perforation of 8-caliber plate was possible, the test could not be made because the projectiles were all used in firing at the thinner plates.

4. Discussion of results

The effect of shatter of a tungsten carbide projectile on its ability to perforate plate is seen from the survey test to be very similar to that exhibited by shatter of a steel projectile.[2/] The result of an impact may be classified into one of four groups, namely (1) no perforation, no shatter, (2) perforation, no shatter, (3) no perforation, shatter, and (4) perforation, shatter. The criterion of shatter is taken to be the occurrence of a rough surfaced, oversized hole in the armor. The striking velocity, obliquity of attack, and plate thickness variables group into four regions, in each of which a single type of behavior results, and the regions may be separated by curves or bands of perforation limit velocity and shatter velocity. The shatter velocity appears to be relatively independent of plate thickness, but strongly affected by changes in obliquity of attack.

2/ High-velocity terminal ballistic performance of caliber .30 AP M2 cores, NDRC Report A-282 (OSRD No. 3889) by R. J. Emrich and C. W. Curtis.



	Nose Length (caliber)	Shape	Type
½T	½	0.50/0.50 Tangent	M-24-18
½C	½	Cone	M-24-24
1T	1	1.25/1.25 Tangent	M-24-20
1S	1	1.25/2.50 Secant	M-24-23
1C	1	Cone	M-24-25
2T	2	4.25/4.25 Tangent	M-24-22

Fig. 7. Effect of nose shape on performance of monobloc caliber .244 projectiles (89% WC, 11% Co) against homogeneous armor BHN 270. Shatter occurred with all shots. NPS is no perforation, shatter; PS is perforation, shatter. e/d = 2.06; projectile weight = 7.6 gm; w/d³ = 1.15 lb/in³

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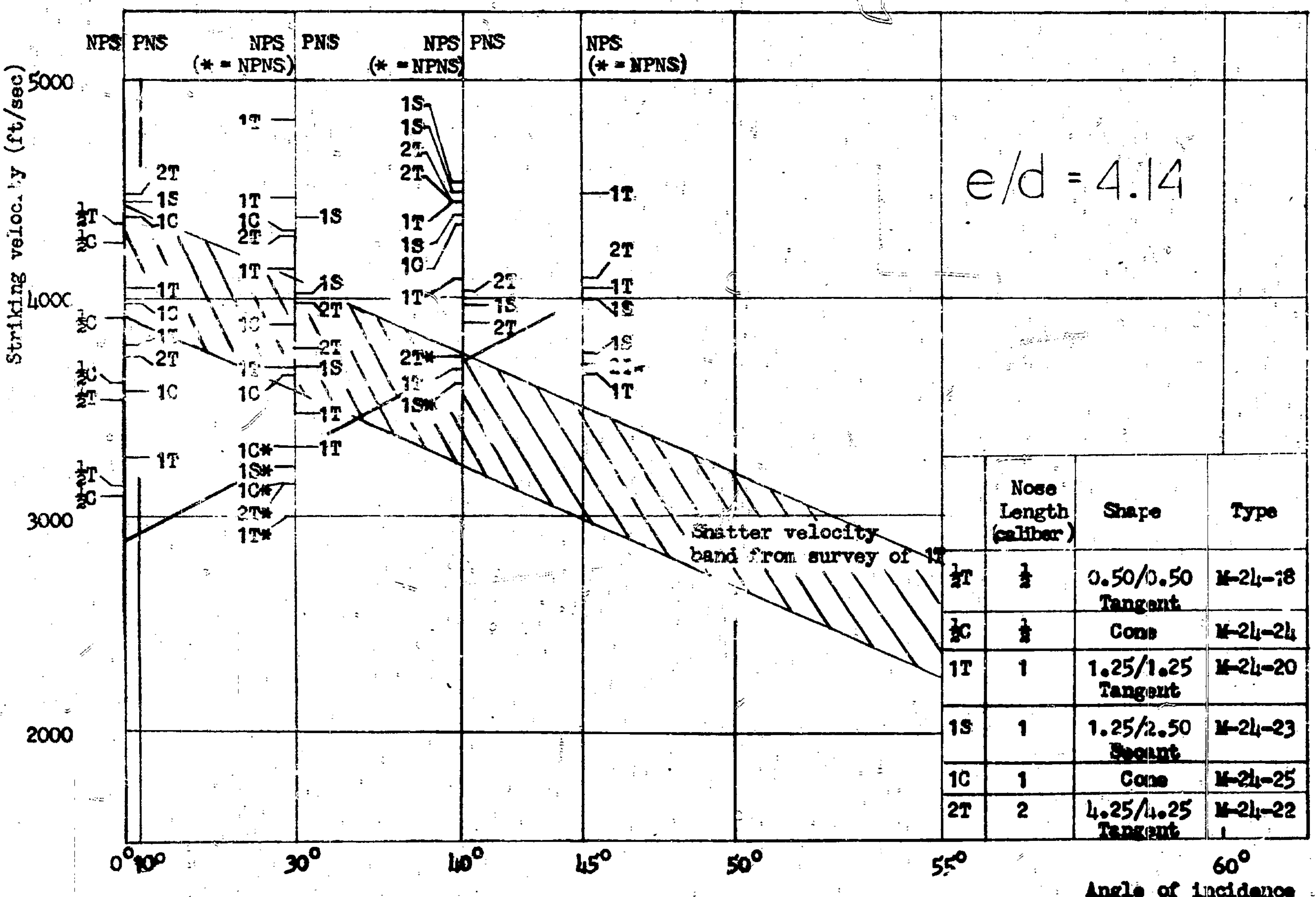

	Nose Length (caliber)	Shape	Type
½T	½	0.50/0.50 Tangent	M-24-18
½C	½	Cone	M-24-24
1T	1	1.25/1.25 Tangent	M-24-20
1S	1	1.25/2.50 Secant	M-24-23
1C	1	Cone	M-24-25
2T	2	4.25/4.25 Tangent	M-24-22

Fig. 8. Effect of nose shape on performance of monobloc caliber .244 projectiles (89% WC, 11% Co) against homogeneous armor BHN 270. NPS is no perforation, shatter; PNS is perforation, no shatter; * is NPNS, no perforation, no shatter. $e/d = 4.14$; projectile weight = 7.6 gm; $w/d^3 = 1.15$ lb/in^3

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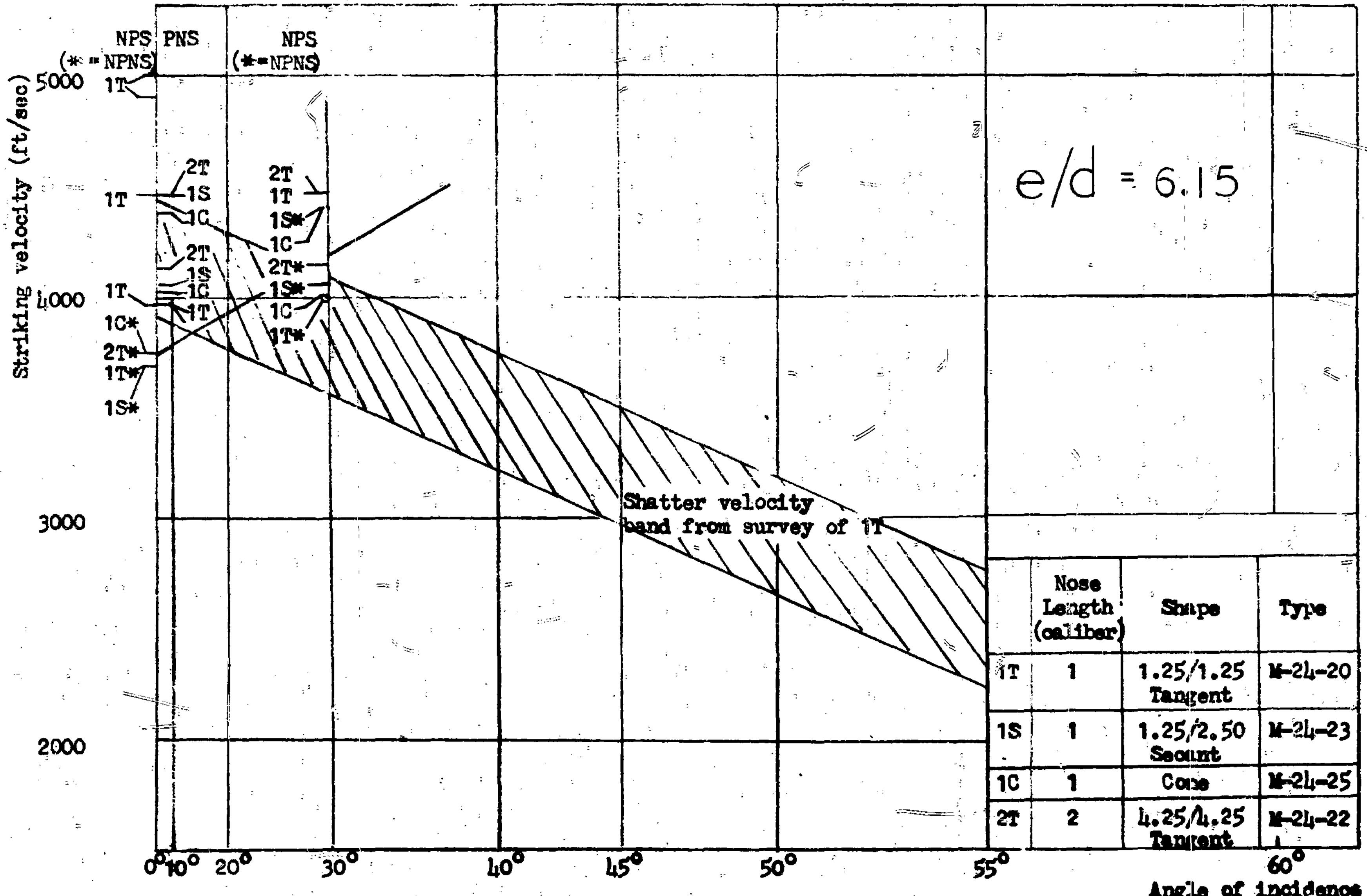

	Nose Length (caliber)	Shape	Type
1T	1	1.25/1.25 Tangent	M-24-20
1S	1	1.25/2.50 Secant	M-24-23
1C	1	Cone	M-24-25
2T	2	4.25/4.25 Tangent	M-24-22

Fig. 9. Effect of nose shape on performance of monobloc caliber .244 projectiles (89% WC, 11% Co) against homogeneous armor BHN 255. NPS is no perforation, shatter; PNS is perforation, no shatter; * is NPNS, no perforation, no shatter. e/d = 6.15; projectile weight = 7.6 gm; w/d^3 = 1.15 lb/in.^{3}

At critical values of obliquity, and probably at critical values of plate thickness, the limit velocity for perforation changes abruptly, and these critical values are determined by the intersection of the curves of shatter velocity and of perforation limit velocity. The occurrence of a shatter gap is noted.

Thus the limit velocity for perforation of 2-caliber plate rises 1000 ft/sec when the obliquity of attack changes from 45° to 50°, although a 5° change of obliquity on either side of the critical obliquity results in only about 200-ft/sec change in limit velocity. A shatter gap appears on 4-caliber plate at 30° obliquity of attack; perforation is possible with velocities from 3100 ft/sec to about 3600 ft/sec, but with higher velocities, even up to 4800 ft/sec, perforation is not achieved.

In the two instances cited in the preceding paragraph the magnitudes of the increases in perforation limit energy are 60 percent and more than 80 percent. This is an indication of the extra amount of energy required for perforation when shatter is encountered.

The study of the effect of nose shape under the conditions of hyper-velocity, high-obliquity attack of the 2-caliber plate reveals that no marked advantage is possessed by any one nose shape over any other. This result may be attributed to the fact that all the projectiles shattered.

Against 4-caliber plate, however, the projectiles with ½-caliber nose length failed to perforate even at 0° obliquity of attack at all velocities. All the projectiles of longer nose length perforated 4-caliber plate at 0° obliquity at all velocities; with certain velocities the 1.25/2.50 secant and 4.25/4.25 tangent shapes perforated at 30° and 40° obliquity. The differences in performance against this plate are well correlated with the occurrence of shatter; the shatter-velocity bands for the 1.25/2.50 secant and 4.25/4.25 tangent shapes are 400 ft/sec to 600 ft/sec higher than that for the 1.25/1.25 tangent shape tested in the survey, whereas the shatter-velocity band for the projectiles of short nose length is at least 1500 ft/sec lower than that for the survey-tested shape.

5. Summary

(1) Shatter behavior of tungsten carbide which is similar to that of steel projectiles has been demonstrated.

(2) Under conditions of high-velocity, high-obliquity attack, changes in nose shape have little effect on the projectile's perforating ability, since shatter occurs in all cases.

(3) Projectiles with the more pointed noses perforate greater thicknesses of armor at low obliquities.

It is apparent from the results that some means of avoiding shatter other than changes in nose shape must be employed when tungsten carbide projectiles are fired at hypervelocities.

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Monthly Report OTB-7 (OSRD-4720)
February 15, 1945

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Projects OD-154, OD-160

Princeton University
W. Bleakney, Supervisor

THIRD REPORT ON BLAST DEFLECTORS FOR THE SUPPRESSION OF DUST

by J. J. Slade, Jr.

Abstract

The restrictions under which the solution of the problem of obscuration has been sought up to the present and the feasibility of removing some of these limitations are discussed.

Three blast deflectors for the 76-mm gun to be offered as possible partial solutions of the problem are described. A deflector for the 37-mm gun is also described.

1. Restrictions

Until recently some severe restrictions have been imposed on attachments designed to reduce obscuration from dust and smoke. One restriction, that the attachment should not change the recoil characteristics of the gun,[1] has long since been removed, but others have remained that have limited the types of deflectors it was felt could be tried. The limitations that have presented the greatest handicaps are (i) the maximum weight of the deflector, (ii) intolerance of back blast, (iii) intolerance of upward deflection of the gases.[2]

Up to now we have understood that the deflector was to be placed on the guns now in use as a field modification, or at least a modification that would require no more than the threading of the ends of the tubes. This restricts the weight of the attachment, since the elevating mechanism of the gun cannot operate properly against too great an unbalance. In recent talks with members of the Tank Destroyer and Armored Boards it became clear, however, that a solution should be contemplated even if it implied the redesign

1/ "Preliminary report on blast deflectors for the suppression of dust," by J. J. Slade, Jr., included in OTB-1 (OSRD No. 4077).

2/ "On the design of a muzzle blast deflector," by J. J. Slade, Jr., included in OTB-4 (OSRD No. 4357).

of gun and carriage. It appears then, that although there is pressing need for a light attachment that will reduce obscuration, there is also need for something more drastic than hitherto contemplated that will not merely reduce but if possible eliminate obscuration.

The restrictions on back blast may also be partially removed. The back blast resulting from the use of the authorized brake M2 on the 76-mm gun appears not to be excessive. This is an important consideration. The brake M2, which raises a great deal of dust, nevertheless reduces obscuration by virtue of throwing the dust back of the gunner's position where the wind has less chance of blowing it into the line of sight. The performance of all the deflectors that have been tried would be improved if the side jets were deflected backwards.

For some time we have endeavored to determine what limits the asymmetry that may be allowed in the blast from the muzzle of a gun as mounted at present. Although it is apparent that a downward thrust at the muzzle is undesirable, still there must be some non-zero limit to this thrust below which no ill effects result. It is certainly desirable to take advantage of this permissible thrust. The two critical factors seem to be that (i) a non-symmetrical pressure field will cause the projectile to yaw, (ii) that the elevating mechanism is relatively weak. With regard to the first of these, it seems possible to maintain a symmetrical core around the projectile while it passes through the attachment even when high unsymmetrical pressures exist just outside the baffles.[2/] Even in the case of a simple attachment that has large port areas it would seem that the speed of the emerging gases is great enough to keep the unsymmetrical shocks from reaching the path of the projectile during the time of passage, if the asymmetry of the ports is not too great. With regard to the second factor, we have the following letter from Maj. P. W. Constance, Ordnance Department:

> In reply to your letter of 11 November 1944, the Carriage Branch, Industrial Service, advises that the elevating mechanism of the 90 mm Gun Carriage, T5E2, will withstand a force applied in a vertical plane at the end of the tube of 5900 lbs., and the 76 mm. Carriage Mechanism about 4500 lbs. It is pointed out, however, that there will be an initial force applied to the mechanism in an opposite direction due to the kick-up caused by the powder

couple which will then be followed by the kick-down reaction of the tube because of an upward deflection of gases through the deflector. This may set up harmful vibrational forces and the Carriage Branch strongly advises against such an arrangement.

The only vibrations that can be set up by the two impulsive thrusts, regardless of their directions and times of application, are those corresponding to the natural frequencies of gun, mount, and carriage. These frequencies are low and there is high damping, so that we are inclined to disregard the last objection. It is difficult to estimate what deflection of the gases would produce an effect on the mechanism corresponding to the static loads given in Major Constance's letter, but only slight deflections are being considered as described in the next section.

It must be remembered that no motion of the tube will take place as a result of the downward thrust until after the projectile has left the muzzle, so that the trajectory will not be affected.

2. Dust suppressors for 76-mm gun

As a result of observations and conversations at Camp Hood, it has become apparent that no device that is a simple field modification can solve the problem completely. In the extreme dug-in position the muzzle of a tank-destroyer gun may be only a few inches above the ground, regardless of caliber. Even a very small fraction of the gas from a gun of large caliber will produce obscuration under these conditions if the ground is dry. The solution that offers some hope at present is a combination of deflector and blast mat. Tanks are unable to make use of blast mats, but tanks will seldom fire from extreme dug-in positions such as used by tank destroyers. An attachment that keeps the concentrated blast from the ground will aid in preserving the mat and thus make possible the use of light mats. A deflector that spreads the jet uniformly around the muzzle of the gun in a horizontal plane would probably be easiest on a mat, but this type of diffuser is not the one that produces least obscuration in the absence of a mat. The deflector should be designed for least obscuration without the use of a mat.

Three deflectors are being offered as a possible immediate partial solution of the problem. In all three the port areas are nonsymmetrical about the horizontal plane through the bore axis. Solid walls are being

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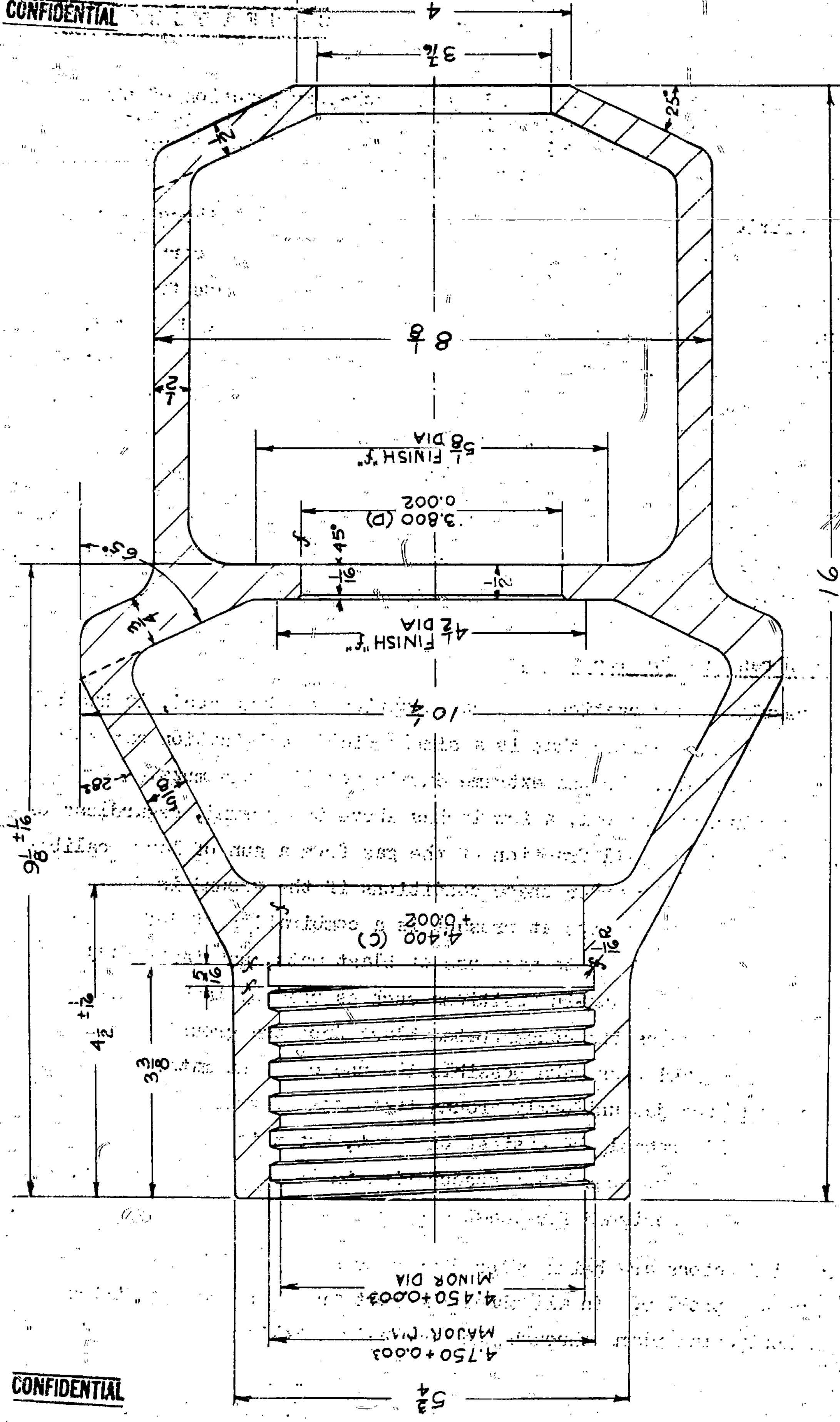

FIG. 1. DUST SUPPRESSOR NO.IVA FOR 76mm GUN, MODIFICATION OF THE TWO-BAFFLE STANDARD ORDNANCE BRAKE M2.

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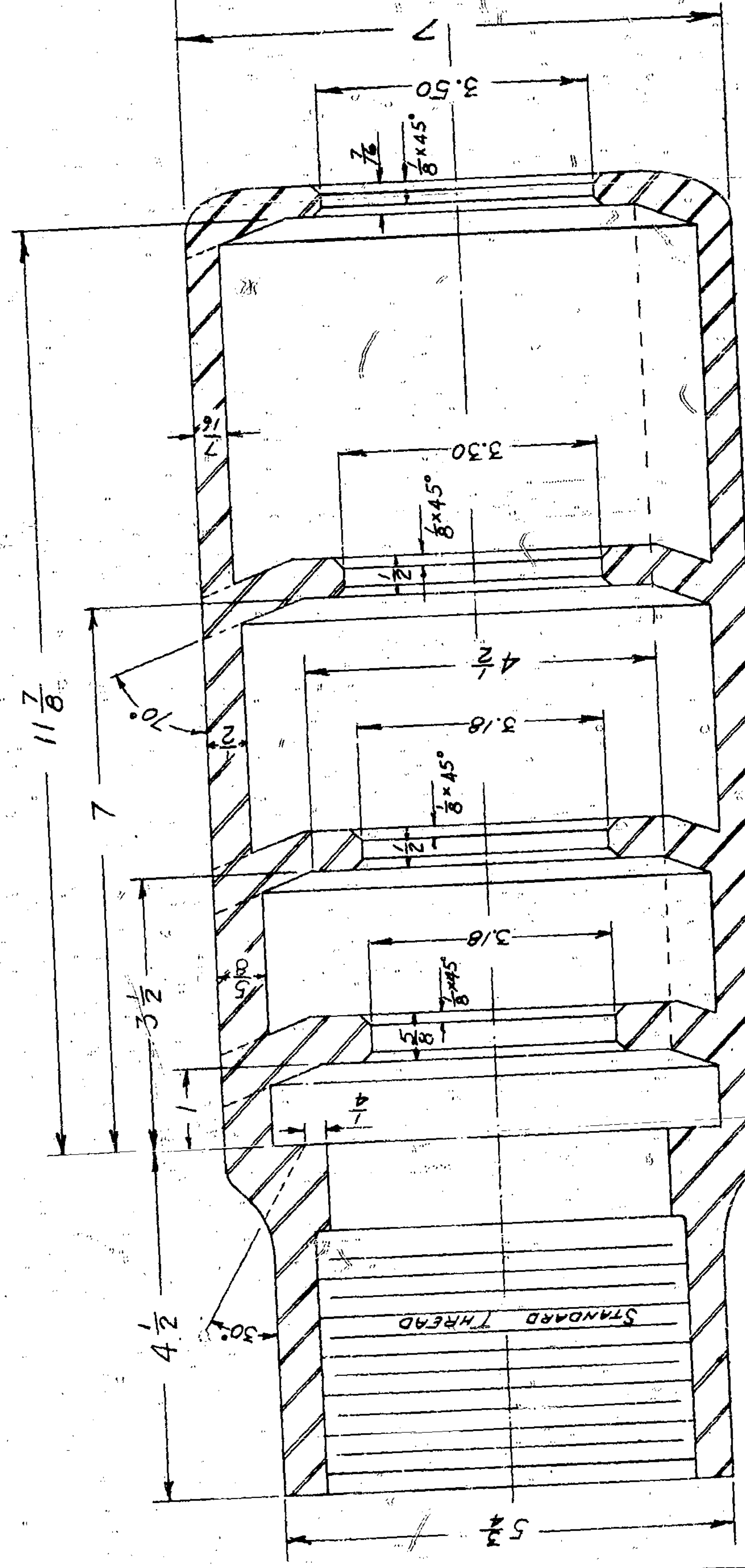

FIG. 2. DUST SUPPRESSOR NO. C1-A FOR 76mm GUN.

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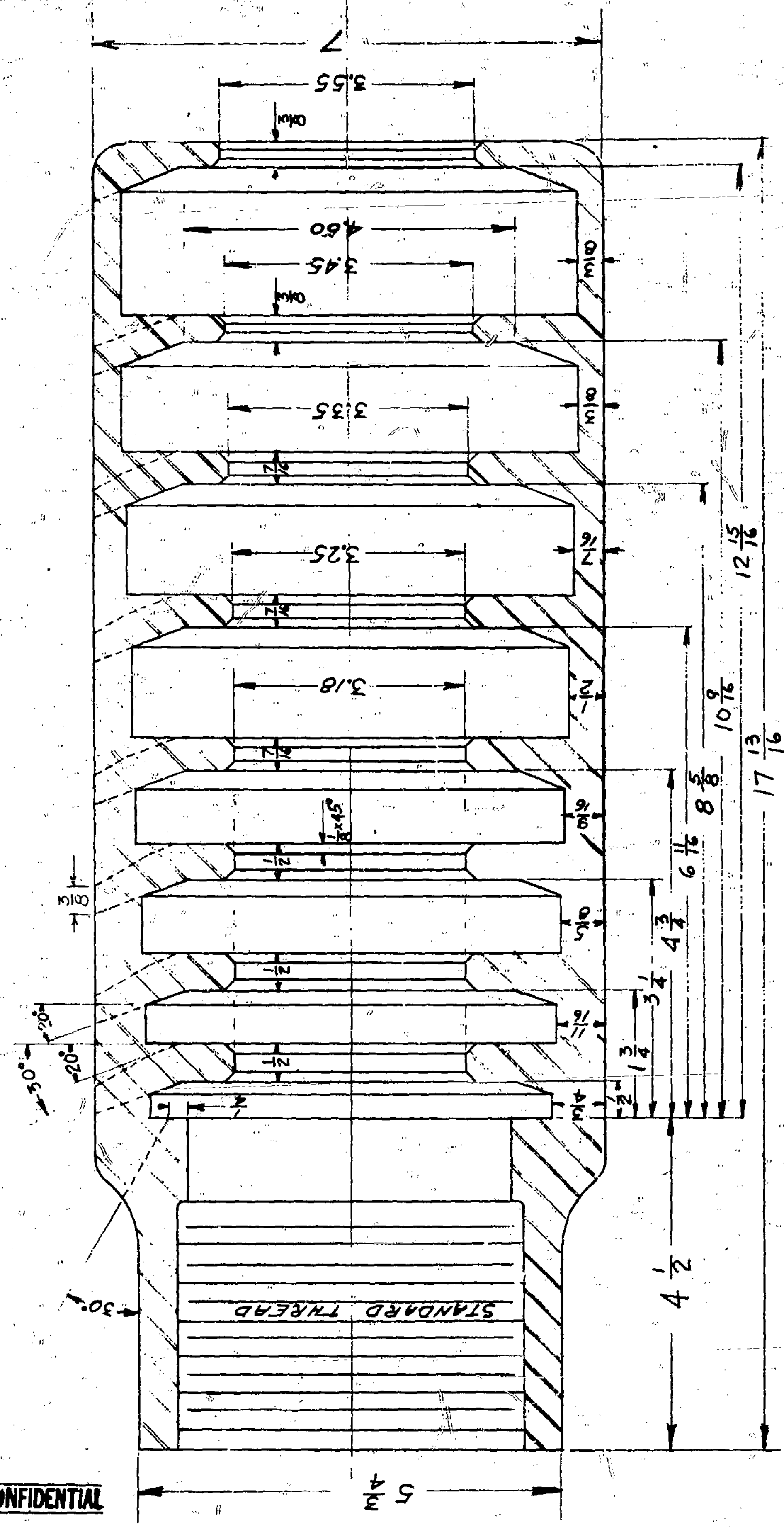

FIG.3. DUST SUPPRESSOR NO. C4-A FOR 76mm GUN.

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Fig. 4. Dust suppressor No. G.E. 40 for 37-mm gun.

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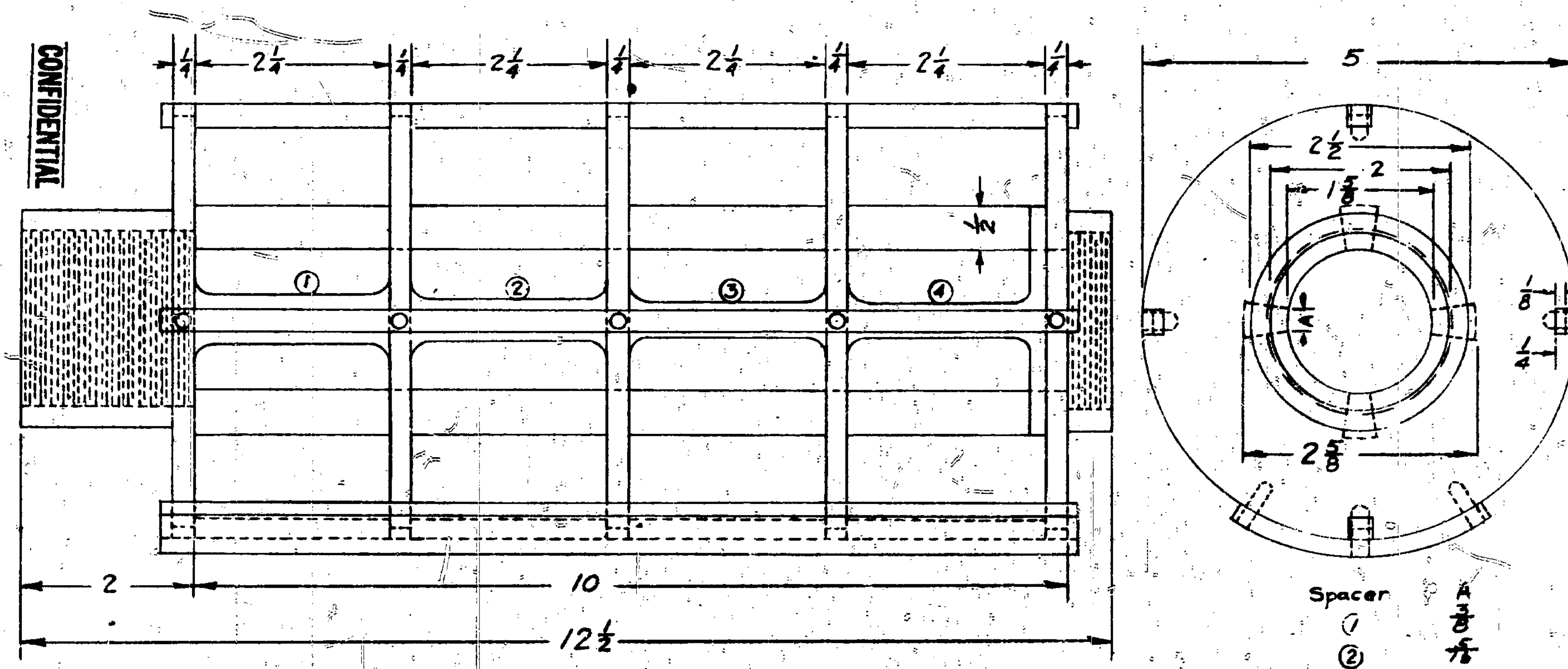

Spacer	A
①	3/8
②	5/16
③	1/4
④	1/4

FIG. 5. DUST SUPPRESSOR NO. 40GE FOR 37mm GUN.

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left through an arc of 90° at the bottom and an arc of 60° at the top. Some experimentation with the port areas will be possible on the 76-mm gun when the effects of the asymmetry on the elevating mechanism are observed.

Figure 1 shows a modification of the two-baffle standard ordnance brake (M2). The authorized forging has been used in constructing this brake. The inner baffle takes the standard bushing which reduces the hole to a diameter of 3.18 in. In allowing a larger expansion chamber between the muzzle and first baffle and simplifying the construction of the second baffle, the resulting brake becomes almost identical with the more recent German brakes, such as the one on the 7.5-cm tank gun KwK42. Since it seems quite certain that the jet issuing through the hole in the first baffle does not expand greatly, the flanges in the outer baffle were eliminated.

Figures 2 and 3 show modifications of C1 and C4 brakes, respectively. The holes in the baffles have been made as small as seemed compatible with proper clearance, since it is the residual jet that produces the more serious obscuration. The side jets are deflected backward though slightly less than in the standard brake.

3. Dust suppressor for 37-mm gun

Figure 4 shows dust suppressor No. GE 40 based on ideas submitted by the General Electric Company. Wire screen is wound around a mandrel which is shown in Fig. 5. Except for the outer rods, the mandrel is turned from a solid steel cylinder. Since the throttling of the gas by the screen will leave a large residual forward jet, screw threads have been provided at the outlet hole to experiment with a nozzle. The bottom plate is tentative; it is proposed to experiment with top and bottom plates.

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Project AC-73

Duke University
P. M. Gross, Supervisor

CALCULATED LEADS FOR AERIAL GUNNERS USING THE API-M8 CALIBER .50 PROJECTILE AND THE T44 CALIBER .30 FRANGIBLE PROJECTILE

by Harold A. Scheraga and Marcus E. Hobbs

Abstract

A frangible projectile (Ordnance notation T44) has been developed for training aerial gunners by having them fire the projectile from a bomber at a lightly armored target airplane. The present report shows how the calculated leads the gunner must give to obtain hits when using the T44 round compare with those he should give to obtain hits under conditions of combat. The calculations are based on the assumption that the fighter travels a theoretical lead pursuit curve.

The T44 frangible projectile was developed with the idea that if the bomber and fighter velocity and the sight reticle were properly scaled a training device for aerial gunners could be made available which would closely reproduce the conditions of combat. The most important single factor considered was that the leads used by the gunner in training would, to his knowledge, be equivalent to those he should use when under actual conditions of combat where he was being attacked by a fighter on a curve of pursuit. The fighter velocity V_F, bomber velocity V_B, and T44 bullet muzzle velocity U_B that have been found practical for training as compared with the assumed conditions for combat are as follows.

Situation	Projectile	Muzzle Velocity U_B (ft/sec)	True Air Speed (mi/hr) Of Fighter V_F	True Air Speed (mi/hr) Of Bomber V_B
Combat	API-M8	2870	325	225
Training	T44	1360	231	160

Calculations of the leads required when the fighter approaches the bomber on a theoretical lead pursuit curve not corrected for aerodynamic factors have been made along the following lines:

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(i) The path of the fighter is represented by[1]

$$\rho = \rho_o \left[\frac{\tan^{\lambda} \frac{1}{2}\theta}{\sin \theta}\right]^{1/(1-\lambda\mu)}. \tag{1}$$

In Eq. (1) ρ is the instantaneous range[2] between the bomber and fighter, ρ_o is the range when $\theta = 90^o$, θ is the sight angle in the plane of action measured (for convenience in the present calculation) off the tail of the bomber and from the bomber flight line, λ is the ratio V_F/V_B of fighter velocity to bomber velocity, and μ is the ratio $V_B/(V_F + 2450)$, where the constant 2450 is the average velocity of a fighter's bullets. The assumptions used in deriving Eq. (1) are given in reference 1. In the present calculations in both the combat and training case the initial range has been chosen as 700 yd and the altitude as 8000 ft.

(ii) The instantaneous range of the fighter as a function of time has been calculated by use of the relation[1]

$$dt = \frac{-\rho_o(\rho/\rho_o)\,d\theta}{V_B(1-\lambda\mu)\sin\theta}, \tag{2}$$

where ρ/ρ_o is defined by Eq. (1).

Defining f and T as

$$f = \left(\frac{\rho/\rho_o}{\sin\theta}\right), \quad T = \int_{\theta_o}^{\theta} f\,d\theta,$$

then t is given by

$$t = \frac{\rho_o}{V_B(1-\lambda\mu)}\,(T_\theta - T_{\theta_o}).$$

The relation for T is integrated graphically.

(iii) The instantaneous ranges of the projectile as a function of t are obtained from Firing Tables FT 0.50 AC-Q-1 and FT 0.30 AC-U-1 as calculated by Aberdeen Proving Grounds.

1/ Elements of theory of aerial gunnery, The Jam Handy Organization (1943), p. 15.

2/ The instantaneous range is defined as the distance between the gunner and the fighter at any instant.

(iv) The contact point between the projectile flight path and the fighter path is determined by the point of intersection of the range-time plot of the projectile path at the correct angle of fire and the range-time plot of the fighter path calculated as indicated in (ii) above. With the range of the contact point thus determined, the angle off at the bullet-fighter contact point is determined from a graph of range versus angle off for the fighter path.

(v) The uncorrected lead is calculated as the difference between the sight angle in the plane of action at the time of firing and the angle determined by a line drawn from the bomber to the bullet-fighter contact point. This lead is then corrected for bullet trail and drop as found in the firing tables and is finally resolved into lead in azimuth and elevation. The terms "azimuth" and "elevation" as used in connection with this correction are defined in the firing tables.

Since training with the T44 projectile has been restricted thus far to the tail hemisphere of the bomber, five cases involving approaches of the fighter in this hemisphere have been calculated. They would appear to cover cases that would be used in training. The results of the calculation are shown in Table I.

In Table I no data are given for ranges less than 200 yd because in the training case the attack is broken off at this range. Further, in rear-quarter attacks the lead gets so small at this range that no serious error can be expected between the combat and training cases if a properly adjusted sight reticle is used for the training case; and in the beam attacks at ranges of the order of 200 yd the centrifugal acceleration on the fighter ("G's") becomes quite large. It appears from the values of r that a reticle 1.50 times the diameter of the combat reticle will be a good average value to make the training case closely approximate the combat case insofar as leads measured in terms of reticle "rads" are concerned.

Table II shows the values obtained for Cases A,B,C,D, and E of Table I by dividing r by 1.50. It may be remarked that 1.50 is the ratio of the 100-percent own-speed relation for the training to that for the combat case.

Table I. Computations for the T44 projectile under training conditions compared with computations for the API-M8 projectile under combat conditions for five cases involving approaches of the fighter in the tail hemisphere of the bomber.

Rear-Quarter Attacks

Situation	θ (deg)	R (yd)	Case A: α = 0° Lead (mil) A	E	Λ	k	r	Case B: α = +45° Lead (mil) A	E	Λ	k	r	Case C: α = −45° Lead (mil) A	E	Λ	k	r
Combat	90																
Training																	
Combat	80																
Training																	
Combat	70																
Training																	
Combat	60	700	74	−7	74	0.74	1.43	85	25	76	0.76	1.54	84	−37	75	0.75	1.52
Training			106	−25	106	.71		128	11	117	.78		124	−64	114	.76	
Combat	50	561	67	−6	67	.76	1.43	64	27	66	.75	1.60	66	−37	68	.77	1.51
Training		567	96	−20	96	.73		103	23	106	.80		100	−63	103	.78	
Combat	40	451	53	−5	53	.72	1.47	48	26	55	.74	1.53	46	−31	53	.72	1.55
Training		460	78	−17	78	.70		71	23	84	.76		71	−50	82	.74	
Combat	30	359	41	−5	41	.72	1.46	34	22	44	.77	1.52	32	−25	41	.72	1.59
Training		370	60	−13	60	.70		53	23	67	.79		52	−42	65	.76	
Combat	20	275	32	−4	32	.82	1.53	25	19	34	.87	1.53	23	−19	32	.82	1.62
Training		287	49	−10	49	.83		43	22	52	.88		37	−33	52	.88	

Beam Attacks

Situation	θ (deg)	R (yd)	Case D: α = 0° Lead (mil) A	E	Λ	k	r	Case E: α = +45° Lead (mil) A	E	Λ	k	r
Combat	90	700	91	−8	91	0.79	1.44	128	−3	91	0.79	1.46
Training			131	−26	131	.76		187	−21	133	.77	
Combat	80	527	86	−6	86	.76	1.45	116	10	85	.75	1.53
Training		534	125	−20	125	.74		174	−2	130	.76	
Combat	70	408	81	−6	81	.75	1.48	101	21	82	.76	1.54
Training		418	120	−16	120	.74		155	14	126	.78	
Combat	60	322	72	−5	72	.72	1.61	84	32	75	.75	1.55
Training		334	116	−12	116	.77		132	34	116	.77	
Combat	50	258	67	−3	67	.76	1.45	66	31	68	.77	1.44
Training		270	97	−11	97	.73		94	36	98	.74	
Combat	40	208	55	−2	55	.74	1.47	48	29	55	.74	1.49
Training		220	81	−8	81	.73		69	35	82	.74	
Combat	30											
Training												
Combat	20											
Training												

Symbol	Unit	Definition
α	deg	Inclination of plane of action to horizontal.
θ	deg	Sight angle off tail in the plane of action at the time bullet is fired. Not to be confused with angle at which guns are fired. In all the pursuit-curve-type cases the lead is a lead ("lag") toward the bomber tail away from the sight line.
R	yd	Instantaneous range between the guns and the fighter.
A	mil	Azimuthal lead ("lag").
E	mil	Elevational lead.
Λ	mil	Lead in plane of action.
k	—	Ratio of Λ to Λ_o, where $\Lambda_o \equiv (1000\ V_B \sin\theta)/U_B$, and where V_B is true air speed of the bomber, U_B is the bomber bullet muzzle velocity. Λ_o is generally known as the 100% own-speed lead.
r	—	Ratio of the Λ-values calculated for the T44 projectile and the API-M8 at the same angle of sight for equivalent attacks; that is, at $\theta = 60°$, $\alpha = 0°$ the leads are $\Lambda_{T44} = 106$, $\Lambda_{API\text{-}M8} = 74$, and therefore $r = 106/74 = 1.43$.

Table II. Value of r/1.50 for Cases A, B, C, D, and E of Table I.

θ (deg)	r/1.50 for Case A	Case B	Case C	Case D	Case E
90				0.96	0.97
80				.97	1.02
70				.99	1.03
60	0.96	1.03	1.01	1.07	1.03
50	.96	1.07	1.01	0.97	0.96
40	.98	1.02	1.03		
30	.98	1.01	1.06		
20	1.02	1.02	1.08		

It was found that more constant values of r could be obtained by not scaling down the average velocity (the constant 2450 appearing in the definition of μ), of the fighter's bullet. If the fighter therefore gives, in the training case, the same leads (on a "rad" basis) as he would use in combat, the size of the reticle in his sight must be reduced. For values of θ between 20° and 90°, the fighter's reticle in training must be 75 percent of its size in combat. All the data given herein have been calculated on this basis.

It should be noted that all the calculations pertain to pursuit-curve attacks. Calculations for the case of the fighter and bomber flying parallel and antiparallel courses are now under way.

It appears that the frangible projectile should give good training (i) for gunners using "position firing rules" for pursuit-curve attacks, (ii) for gunners using "own-speed" sights for pursuit-curve attacks, and (iii) for gunners using computing sights on pursuit-curve attacks provided the sights are properly adapted for the training case. In the case of "own-speed" sights and fixed sights, the adaptation is quite simple. Adaptation of computing sights will vary in complexity with the particular type sight.

There are several shortcomings of this presentation which the writers recognize. One is that the aerodynamic factors may modify to a significant extent the path the fighter travels. It is felt that until considerably more information is made available as to what paths are actually traveled in a pursuit-curve attack, a reasonable assumption is that the inclusion of such factors will modify absolute values of the lead but may leave the ratio of the leads used in combat and training approximately as found above. Another consideration is the precision of the graphical method used in the calculations. In general, the accuracy is of the order of ± 2 mil in $\underline{\Lambda}$, and since tracking errors are of the order of 2 to 5 mil the error in calculation cannot be regarded as very serious. Since the errors in time of flight of the projectile as obtained from firing tables may also be of the order of 1 to 2 percent, and even more if factors such as the dependence of muzzle velocity on temperature and gun-barrel condition are not considered, the significance of the calculational errors are even further minimized.

ADVANCE RELEASE: This information is tentative and subject to revision.

Project AC-73

Duke University
P. M. Gross, Supervisor

THE EFFECT OF PROJECTILE DIAMETER ON THE AVERAGE MUZZLE VELOCITY FOR THE T44 PROJECTILE

by A. J. Weith, Jr., J. H. Saylor, and Marcus E. Hobbs

Abstract

Some difficulty has arisen with excess dispersion in velocity of the Ordnance-produced T44 frangible projectile round. Since several factors were believed to affect the diameter of the molded projectile, firings have been made to determine the effect of variations in the diameter on average muzzle velocity. All shots were fired through the same muzzle of a Browning AC M-2 machine gun and a fixed charge of Du Pont No. 4759 smokeless powder was used. The results indicate a definite but small trend toward increasing muzzle velocity with increasing diameter. Certain possible simplifications in the process of manufacture are suggested by these results.

The T44 projectile is now molded from a composition of finely divided lead powder and bakelite binder at several different molding plants. Variations in time of cure, pressure, temperature of curing, and so forth are believed to influence the diameter of the finished projectile to a significant extent. However, the variable which definitely determines the nominal diameter of the projectile is the cavity size. Cavities are found to vary in size within a particular mold because of the inability of the mold maker to meet better than some nominal tolerance value in his cavity-making operation. In view of the above factors affecting bullet diameter and since some difficulty has arisen with regard to dispersion in the velocity of the Ordnance-produced T44 round, an investigation of the effect of bullet diameters on muzzle velocity was indicated.

Projectiles of the regular T44 composition were molded in several sizes of cavities by the Bakelite Corporation at Bloomfield, New Jersey, under what were considered average conditions. These were then machined to weight and a normal crimping groove was cut in the projectile. They were hand loaded with 0.830 ± 0.002 gm charges of Du Pont No. 4759 smokeless powder and all crimped at a constant load into caliber .30 M-1 primed cases. All powder was obtained from the same 1-lb can of No. 4759 powder. The complete round was then placed in an air thermostat at 24.0 ± 1.5°C for a minimum period of 3 hr. The average relative humidity during this thermostatting was 32 percent.

The rounds were removed from the thermostat one at a time and fired through the same caliber .30 Browning AC M-2 machine gun, using the same barrel throughout. The average velocity over a 50-ft range was determined with an Aberdeen chronograph and was then corrected to give muzzle velocity. The results of the tests and other pertinent data are shown in Table I. Twenty rounds were fired for each case. Three separate loadings of some stock T44 projectiles received several months ago were made to check the internal consistency of the loading procedure. These data are also shown.

Table I. Data from firing 20 rounds each of 7 groups of T44 projectiles in a Browning AC M-2 machine gun.

Bakelite Code for Projectiles	Cavity Size (in.)	Projectile Diameter (in.)		Weight of Projectile (gm)	Average Muzzle Velocity (ft/sec)	σ for Muzzle Velocity
		Average	Average Deviation			
1807-79A*	0.306	0.3050	±0.0002	6.96 ± 0.01	1348	18
1807-79B*	.307	.3065	± .0006	6.94 ± 0.02	1389	14
1807-79C*	.309	.3085	± .0001	6.95 ± 0.01	1415	19
1807-79D*	.310	.3095	± .0002	6.95 ± 0.01	1421	21
T44 Standard RD-42-93	--	.3090	± .0003	6.95 ± 0.02	1401	9
T44 Standard RD-42-93	--	.3090	± .0003	6.95 ± 0.02	1378	9
T44 Standard	--	.3090	± .0003	6.96 ± 0.01	1378	12

*These projectiles were transfer-molded from B.M. 17073, batch 103D, with a cure time of 90 sec at 325°F and 9500 lb/in.²

The data indicate a definite trend toward increasing muzzle velocity with increasing diameter; however, it is rather smaller than was expected in view of the extremes in diameter concerned. The trend is shown graphically in Fig. 1.

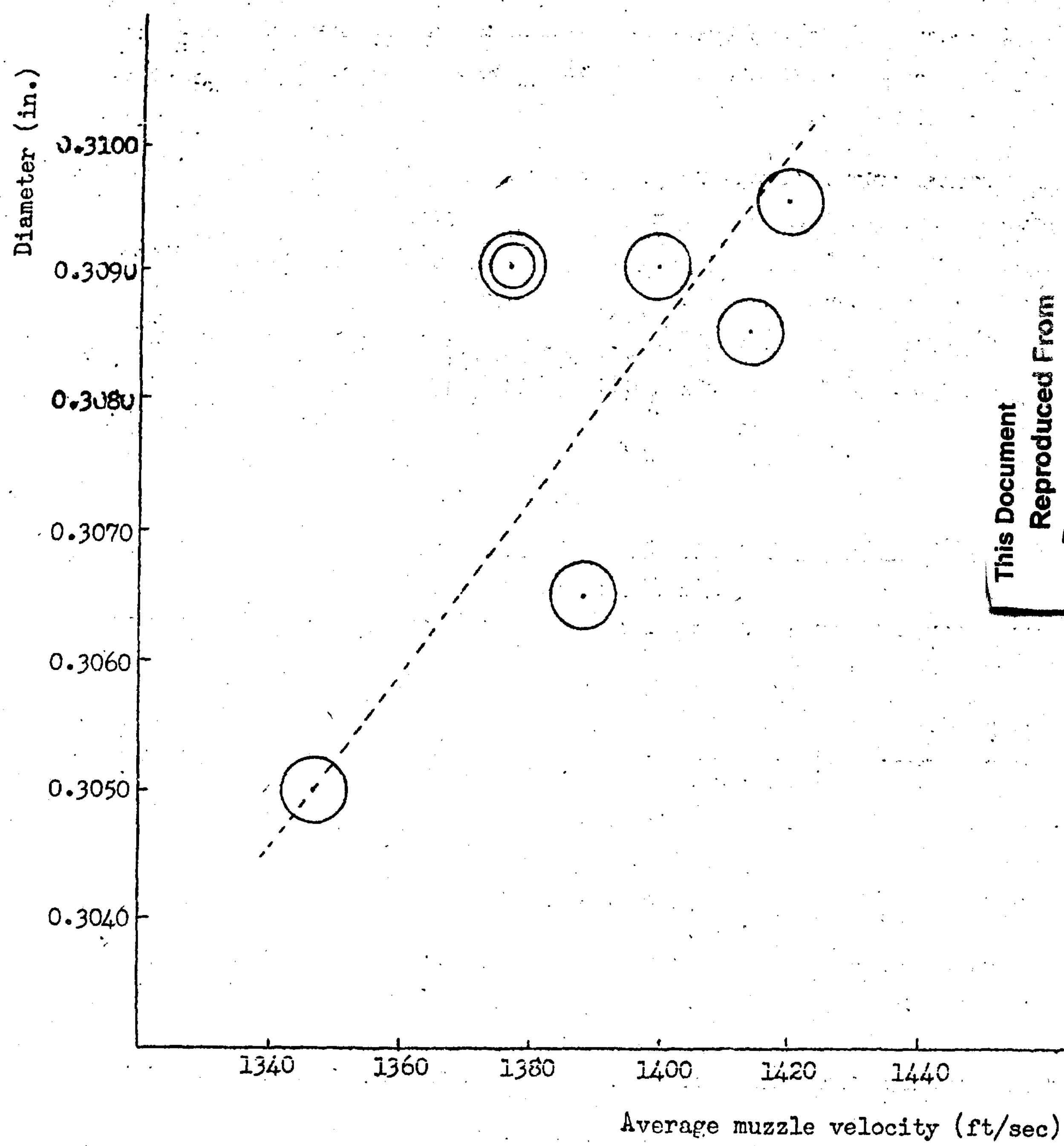

Fig. 1. Graphical representation of muzzle velocity as a function of diameter of projectile. Data plotted were obtained from the firing of 20 rounds each of 7 groups of T44 projectiles in a caliber .30 Browning AC M-2 machine gun.

The results indicate that a tolerance of ±0.0008 to ±0.0010 in. in the normal diameter of 0.3080 in. should not have a serious effect on the average muzzle velocity obtained. Since such tolerances can probably be met rather well in production, it would appear desirable to determine whether the present producing facilities could meet such a tolerance and thus possibly eliminate the present practice of resizing all projectiles. Some of the projectiles produced are slightly eccentric in cross section, and it is understood that resizing is also necessary to eliminate this variable. The eccentricity is quite small (approximately 0.0002 to 0.0003 in.), and both the small σ value and the relatively small dispersion in average muzzle velocity with some regular unsized T44 projectiles would indicate that the eccentricity probably is not a serious factor.

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ABSTRACT:

The theory of the variation of the resisting force during the penetration cycle of a projectile is summarized for three cases as a step toward the solution of the practical problems of fuze setting and target and projectile designs. Moreover, cal 0.244 projectiles of one nose-shape have been tested in a survey against 2-, 4-, and 6-cal-homogeneous armor. Blast deflectors for the suppression of dust in guns are described. A comparison is made of calculated leads and those which a gunner must give in a fighter airplane travelling a theoretical lead pursuit curve. Finally, the effect of the projectile diameter on the average muzzle velocity for the T44 projectile is investigated.

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